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Methodological Workshop on the Management of Tuna Fishing Capacity

Stock status, data envelopment analysis, industry surveys and management options

8–12 May 2006
La Jolla, California, United States of America

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Methodological Workshop on the Management of Tuna Fishing Capacity

Stock status, data envelopment analysis, industry surveys and management options

8–12 May 2006
La Jolla, California, United States of America

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Preparation of this document

These Proceedings present an outcome of the Methodological Workshop on the Management of Tuna Fishing Capacity: Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options. It was hosted by the Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, United States of America, from 8 to 2 May 2006.

This Workshop was organized by FAO's Project on the "Management of tuna fishing capacity: conservation and socio-economics", which was financed by the Government of Japan. It was undertaken in collaboration with and with financial and in-kind support of (i) most tuna agencies and programmes, (ii) other international and national fisheries institutions involved in tuna fishing, fisheries research and management (including those of tuna fishing industry) and (iii) some universities. They included, respectively:

i. the Forum Fisheries Agency (FFA), IATTC, the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Secretariat of the Pacific Community (SPC);
ii. the Japan Federation of Tuna Fisherman's Association (Japan Tuna), the National Fisheries Service (NMFS), the National Research Institute of Far Seas Fisheries (NRIFSF), the World Tuna Purse-Seine Organization (WTPO); and
iii. the College of William and Mary (CWM) and the University of California, San Diego (UCSD).

Shortly after its commencement, the Project established an external Technical Advisory Committee (TAC) composed of experts affiliated with the tuna agencies and programmes and some other institutions involved in tuna fishing, fisheries research and management to foster the collaboration with these institutions. From 26 to 28 March 2003 the Project organized the first meeting of TAC to:

- review methods for the estimation of fishing capacity and their data requirements;
- determine the applicability of these methods for tuna fisheries; and
- finalize proposals of the Studies to be carried out by the Project.

The subjects of these Studies were:

- tuna resources and fisheries;
- the quantification of tuna fishing capacity;
- the demand for tuna raw materials and products and their prices; and
- the management of tuna fisheries, particularly through controlling fishing capacity.

From 15 to 8 March 2004, the second meeting of TAC was held in Madrid, Spain to:

- review the outcome of the Studies implemented by the Project and
- make recommendations on tuna fishing capacity management and future activities of the Project.

The second meeting of TAC also prepared a Statement, which was presented at the Technical Consultation to Review Progress and Promote the Full Implementation of the International Plan of Action (IPOA) to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated (IUU) Fishing and the IPOA for the Management of Fishing Capacity (Rome, Italy, 24–29 June 2004). The papers resulting from the Studies were published in 2005 as FAO Fisheries Proceedings No. 2 entitled "Proceedings of the Second Meeting of the Technical Advisory Committee of the FAO Project

Management of tuna fishing capacity: conservation and socio-economics Madrid (Spain), 15-18 March 2004."

As a result of recommendations of the second meeting of TAC, the Project organized the Workshop, the outcome of which is presented in these Proceedings. Its objectives were:

- to develop a method for the estimation of tuna fishing capacity from stock assessment-related information;
- to determine the feasibility of: (i) routinely collecting input data for the so-called Data Envelopment Analysis (DEA); and (ii) performing industry surveys of tuna fishing capacity utilization;
- to relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity;
- to review the factors affecting fishing capacity (like the number of vessels and their physical characteristics) that could be regulated by fisheries authorities;
- to review the existing measures for managing tuna fishing capacity and, possibly, to identify additional options for such measures in the context of the outcome of addressing the above-mentioned objectives;
- to prepare a Statement of participants of the Workshop; and
- to formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and the other institutions participating in the Workshop.

After the Workshop, the papers presented were revised in response to comments received during the Workshop and technically edited. The papers are included as part of these Proceedings together with the Report of the Workshop. The Statement prepared by the Workshop is enclosed in the Report. That Statement was presented at the Meeting of Tuna Regional Fisheries Management Organizations, which was held in Kobe, Japan, from 22 to 26 January 2007.

Abstract

These Proceedings include the report and papers presented at the Methodological Workshop on the Management of Tuna Fishing Capacity: Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options. The Workshop was hosted by the Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, United States of America, from 8 to12 May 2006 as an activity of FAO's Japan-funded Project on the "Management of tuna fishing capacity: conservation and socio-economics". The Workshop was organized by the Project in collaboration with and with financial and in-kind support of: (i) most tuna agencies and programmes; (ii) other international and national fisheries institutions involved in tuna fishing, fisheries research and management (including those of tuna fishing industry); and (iii) some universities.

The objectives of the Workshop were:

1) to develop a method for the estimation of tuna fishing capacity from stock assessment-related information;
2) to determine the feasibility of: (i) routinely collecting input data for the so-called data envelopment analysis (DEA); and (ii) performing industry surveys of tuna fishing capacity utilization;
3) to relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity;
4) to review the factors affecting fishing capacity (like the number of vessels and their physical characteristics) that could be regulated by fisheries authorities;
5) to review the existing measures for managing tuna fishing capacity and possibly, to identify additional options for such measures in the context of the outcome of addressing the above-mentioned objectives;
6) to prepare a satement of participants of the Workshop; and
7) to formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and the other institutions participating in the Workshop.

The papers presented in these Proceedings include those associated with objectives 1 to 5. The report documents presentations made at and the discussions carried out during the Workshop, their conclusions and the recommendations. The Statement prepared by the Workshop (see Objective 6) is enclosed in the report. That Statement was presented at the Meeting of Tuna Regional Fisheries Management Organizations, which was held in Kobe, Japan from 22 to 26 January 2007.

Bayliff, W.H.; Majkowski, J. (eds.)
Methodological Workshop on the Management of Tuna Fishing Capacity: Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options. La Jolla, California, United States of America, 8–12 May 2006.
FAO Fisheries Proceedings. No. 8. Rome, FAO. 2007. 218p.

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Acknowledgements

The organization of the Workshop, the outcome of which is presented in these Proceedings, was possible only due to FAO's Project on the Management of tuna fishing capacity: conservation and socio-economics. This Project was financed by the Government of Japan. The Project organized the Workshop in collaboration with and with financial and in-kind support of: (i) most tuna agencies and programmes; (ii) other international and national fisheries institutions involved in tuna fishing, fisheries research and management (including those of tuna fishing industry); and (iii) some universities. They included, respectively:

- the Forum Fisheries Agency (FFA), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Secretariat of the Pacific Community (SPC);
- the Japan Federation of Tuna Fisherman's Association (Japan Tuna), the National Fisheries Service (NMFS), the National Research Institute of Far Seas Fisheries (NRIFSF), the World Tuna Purse-Seine Organization (WTPO);
- the College of William and Mary (CWM) and the University of California, San Diego (UCSD).

These institutions contributed to the preparatory technical work for the Workshop, including the implementation of various studies, which were documented in the papers presented at the Workshop. They also financed the participation of their experts at the Workshop.

Shortly after its commencement, the Project established an external Technical Advisory Committee (TAC) composed of experts affiliated with the Tuna Agencies and Programs and some other institutions involved in tuna fishing, fisheries research and management to foster the collaboration with these institutions. The Members of TAC at the time of holding the Workshop are listed below.

- Dr Robin Allen, Director, Inter-American Tropical Tuna Commission (IATTC).
- Mr Alejandro Anganuzzi, Secretary, Indian Ocean Tuna Commission (IOTC).
- Dr John Annala, Chair, Stock Assessment Group (SAG), Commission for the Conservation of Southern Bluefin Tuna (CCSBT).
- Dr John Hampton, Manager, Oceanic Fisheries Programme (OFP), Secretariat of the Pacific Community (SPC).
- Dr James Joseph, Consultant.
- Dr Peter Miyake, Scientific Advisor, Japan Tuna Fisheries Co-operative Association.
- Dr Julio Morón, Assistant Director, Organización de Productores Asociados de Grandes Atuneros Congeladores (OPAGAC) and, till May 2003, Secretary, World Tuna Purse Seine Organization (WTPO).
- Dr Chris Reid, Market Advisor, Forum Fisheries Agency (FFA).
- Dr Victor Restrepo, Assistant Executive Secretary, International Commission for the Conservation of Atlantic Tuna (ICCAT).
- Dr Suba Subasinghe, Director, INFOFISH.
- Dr Naozumi Miyabe, Director, Temperate Tuna Resources Division, National Research Institute of Far Seas Fisheries (NRIFSF).

The TAC recommended the organization of the Workshop.

The editors of these Proceedings are grateful to the Government of Japan, the institutions and persons listed above, the authors of the papers included as part of

these Proceedings and all the participants of the Workshop for their collaboration and support of the Workshop. Only thanks to this collaboration and support, was it possible to produce these Proceedings.

Report of the Workshop

1. OPENING

Dr Robin Allen, Director of the Inter-American Tropical Commission (IATTC), the organization hosting the Workshop and its Chairman, welcomed the participants.

On behalf of the Food and Agriculture Organization of the United Nations (FAO) and its Project on the Management of Tuna Fishing Capacity, which organized the Workshop, Dr Jacek Majkowski, Convener of the Workshop, thanked the participants for:

- finding funds for their travel to La Jolla; and
- the substantial technical work preparatory to the Workshop, which was done in a very timely manner.

He stated that the FAO and its Project are grateful to the organizations that strongly supported the organization of the Workshop and that provided significant in-kind contributions (see Programme of the Workshop in Appendix I). He expressed particular thanks to:

- the IATTC as the host of the Workshop and its Director and other staff members for making the arrangements for the Workshop; and
- the government of Japan, which is financing the Project that organized the Workshop.

Referring to several substantial objectives of the Workshop (see Programme of the Workshop in Appendix I), Dr Majkowski indicated that he was looking forward to the active participation of all the participants in the Workshop, which would allow these objectives to be fulfilled.

2. INTRODUCTION OF PARTICIPANTS

The Chairman asked the participants of the Workshop to introduce themselves, indicating their institutional affiliations. These are listed in Appendix II.

3. ADOPTION OF THE PROVISIONAL AGENDA

The provisional Agenda (Appendix III) was adopted without any changes. The list of papers to be presented at the Workshop (Appendix IV) was also adopted.

It was decided to include a glossary of terms (Appendix V).

4. LOGISTIC ARRANGEMENTS FOR THE WORKSHOP

The Director of the host organization (IATTC) and Convener of the Workshop presented logistic arrangements for the meeting. The Convener of the Workshop suggested the following rapporteurs

- Jacek Majkowski – Agenda Items 1 to 6
- John Hampton and Victor Restrepo – Agenda Item 7
- Sachiko Tsuji and Chris Reid – Agenda Item 8
- Peter Miyake and Julio Morón – Agenda Item 9
- Pablo Arenas and Gerald Scott – Agenda Items 10 and 11
- William Bayliff and Sachiko Tsuji – Agenda Item 12
- James Joseph and Naozumi Miyabe – Agenda Item 13
- Jacek Majkowski – Agenda Items 14 and 15
- Fabio Carocci and Jacek Majkowski – overall coordination

5. STATEMENT FROM AND REPORT OF THE WORKSHOP: CONTENT AND LOGISTIC ARRANGEMENTS FOR THEIR PREPARATION

Dr Majkowski, Convener of the Workshop, proposed that the participants make suggestions regarding the content of the Statement during the session associated with Agenda Item 11. The participants agreed that it would be useful to present this Statement to the Meeting of Tuna RFMOs and their members to be held in Kobe, Japan, in January 2007.

6. OVERVIEW OF THE PROJECT AND ITS IMPLEMENTATION

Paper 1: Overview of the Project on the Management of Tuna Fishing Capacity and its implementation

Dr Majkowski explained that his presentation was prepared to place the Workshop in the context of the FAO Project on the Management of Tuna Fishing Capacity. He provided basic information on the Project, particularly its objectives and activities, in the form of studies and meetings. Then, he concentrated on the outcome of the previous meeting organized by the Project (Second Meeting of Technical Advisory Committee of the Project on the Management of Tuna Fishing Capacity, referring to:

- Report of the Second Meeting of the Technical Advisory Committee (TAC) GCP/INT/851/JPN, Madrid, Spain, 15-18 March 2004.
- Bayliff, W.H.; Leiva Moreno, J.I. de; Majkowski, J. (eds.). Second Meeting of the Technical Advisory Committee of the FAO Project “Management of Tuna Fishing Capacity: Conservation and Socio-economics”. Madrid, Spain, 15-18 March 2004. FAO Fisheries Proceedings. No. 2. Rome, FAO. 2005. 336p.

At the end of his presentation, he recalled the objectives of the Workshop (see Appendix I).

7. DEVELOPMENT OF QUANTITATIVE METHODS TO DETERMINE THE DESIRED CHANGE TO FISHING CAPACITY ON THE BASIS OF THE STATUS OF STOCKS

Paper 2: Estimated target fleet capacity for the tuna fleet in the eastern Pacific Ocean, based on stock assessments of target species

Dr Arenas described how the IATTC has handled the issue of carrying capacity of the tuna fleet in the eastern Pacific Ocean (EPO). A target of 158 000 cubic metres (m^3) of carrying capacity has been adopted by the IATTC for the purse-seine fleet. No target carrying capacity has been established for the longline fleet, but catch limits for this gear were established for 2004 through 2006. Factors affecting the fishery and management tradeoffs were discussed. The rationale for the establishment of a target capacity is to keep it at a level that could take the maximum harvest from the fishery, while at the same time ensuring the sustainability of each stock. Historical management measures, assessments and simulation results were reviewed for both gears, with consideration of the multi-gear and multi-species nature of the fishery. It was concluded that the target of 158 000 m^3 for the purse-seine fleet is still appropriate (unless species-specific fishing methods, especially for skipjack, can be developed), but the carrying capacity of the purse-seine fleet is now 20 to 25 percent above it. A target effort of 160 million hooks (about the level of 2001-2002) for the longline fleet was suggested. It was concluded that with the current mix of gears, the capacity of both fleets is above the capacity appropriate for the management of the tuna stocks in the EPO.

Paper 3: Estimates of large-scale purse seine, baitboat and longline fishing capacity in the Atlantic: an analysis based on a stock assessment of bigeye tuna

Dr Restrepo described an approach for estimating fishing capacity based on the results of an age-structured stock assessment, using Atlantic bigeye tuna as an example. The approach provided estimates of output capacity and capacity utilization by gear type, plus estimates of excess capacity based on maximum sustainable yield (MSY). MSY estimates were allowed to vary over time to reflect the observed changes in selectivity for all fisheries combined. The method appeared to be consistent with traditional definitions of fishing capacity in fisheries science and with the technological-economic approach.

Paper 4: A case study of the impact of recent management measures on overall United States Atlantic longline fishing capacity and effort

Dr Scott described a study of recent management actions taken regarding the United States Atlantic pelagic longline fleet and their combined effects on several indicators of fleet effort and capacity for harvesting swordfish. During the period of management over the past decade, the various measures of United States Atlantic pelagic longline fishing effort and capacity have declined. During the past few years, the total catches of United States vessels have been less than the Total Allowable Catches (TACs), based on estimated maximum sustainable yield, for the United States of America, although substantial amounts of dead fish (mostly undersized) have been discarded. Based on information from generalized linear modeling used to standardize the catch rates for stock assessment, the range of relative efficiencies of the different fishing strategies used within the fleet indicates that the capacity of the fleet would be to sufficient to harvest the United States TAC if a greater proportion of the fleet would apply the more efficient fishing strategies already existing within the fleet. Use of information held within similar standardization analyses could be more broadly applied to estimate capacity frontiers among the fleets harvesting tunas and billfishes.

Paper 5: Estimates of large-scale purse-seine and longline fishing capacity in the western and central Pacific based on stock assessments of target species

Dr Hampton outlined the issues related to the estimation and application of capacity measures consistent with stock assessments of tunas in the western and central Pacific Ocean. While it is relatively simple to specify capacity limits consistent with the stock status of various species, there would be a number of difficulties in applying such an approach in practice. First, the multispecies nature of the purse-seine and longline fisheries and the differential stock status of the main species make it difficult, if not impossible, for single gear-specific capacity limits, or, indeed, other broadly-specified effort-based measures, to address equally the stock status of all species simultaneously. Second, the problem of "effort creep" (increases in efficiency of individual vessels, resulting in increased fishing effort without replacing any of the vessels) is significant for capacity and other effort-based management systems. If such measures are employed, it is essential that the limits are regularly reviewed and, if necessary, adjusted downward to counter effort creep. Third, the specification of capacity limits involves, either explicitly or implicitly, an allocation of those limits. Typically, this allocation is based on the current or recent average fleet composition. However, it is shown that altering the mix of gear types, and hence altering the overall size selectivity of the fishery, can produce very different outcomes for stock status and productivity. Therefore, appropriate levels of fishing capacity in one component of the fishery will depend on the fishing capacity of the other components.

General discussion

Link to stock assessment: The Workshop agreed that using an approach to estimate capacity that is based on a stock assessment has several advantages, including:

- using data that are readily available;
- relating to terms that assessment scientists are already familiar with;
- taking into account estimates of stock abundance over time;
- ability to model multiple fisheries simultaneously;

- ability to model changes in fishing efficiency and species targeting over time.

Further development of these methods is encouraged.

The use of stock assessment methods to estimate output-based capacity requires that the definition of fisheries in the stock assessment model be consistent with how the fisheries are defined for the purposes of measuring capacity. For example, tuna stock assessments frequently define fisheries according to set type and area. Such definitions would not be consistent with capacity measurement because purse-seine capacity cannot normally be disaggregated by set type. However, the ability of purse seiners to switch between set types and areas should be incorporated into output-based capacity measures. Data envelopment analysis (DEA) accommodates this by incorporating such variability into the data, which affects the location of the production frontier. While it might be possible to aggregate the assessment results across set types and regions, a better approach when using stock-assessment based approaches for the purpose of capacity estimation might be to re-define the purse-seine fisheries as a single entity, and, as is done in DEA analyses, incorporate the variability in fishing mortality due to set type and area of operation into the data.

Capacity, selectivity and allocation: Several of the papers presented demonstrated that the long-term potential productivity of a stock can be affected by changes in the overall selectivity of the fisheries that exploit it. This is particularly important in cases for which some fisheries capture smaller fish and others capture larger ones, and the relative importance of these fisheries changes over time. Thus, when defining an "appropriate" overall level of capacity for mixed fisheries, there can be different allocation implications, depending on the selectivity pattern that is assumed.

Data and data resolution: In order to utilize output-based measures of capacity (determined either by stock assessment models or methods such as DEA in fisheries management, the output-based measure must be translated into a physical capacity measure, such as vessel numbers or vessel carrying capacity. This requires data on the relationship between fishing effort or catch and the capacity measure.

From the discussion of the papers presented during this and other agenda items, it was apparent that estimates of capacity may be affected by the levels of aggregation in the data. In general, increased aggregation should result in lower estimates of capacity. This generalization is expected to apply to all deterministic methods that attempt to define a "frontier" of maximum output (for example, DEA or the method presented in Paper 3). For this reason, the dependence of estimates of capacity on the level of data aggregation and assumptions should be tested.

8. FEASIBILITY OF (1) ROUTINELY COLLECTING INPUT DATA FOR DATA ENVELOPMENT ANALYSES (DEAS) AND (2) PERFORMING INDUSTRY SURVEYS OF FISHING CAPACITY UTILIZATION

Paper 6: Review of existing information and their potential use for analyses and management of fishing capacity[1]

Dr Tsuji presented an overview of data potentially useful for the management of fishing capacity of tuna fleets. Vessels of about 60 countries take over 95 percent of the global catches of tunas, and most of these participate in regional tuna management schemes. A variety of vessel information has recently become available to the public, but this information must be organized and combined with information on fishing activities and various transactions if they are to be usable for management of fishing capacity. Her paper proposed that restrictions on fishing effort and on catches be combined with restrictions on fishing capacity to manage the fisheries. The management would be based on the results of stock assessments, of course, which would take into account transfers of catch quotas among gear types or fleets and other pertinent developments. Successful implementation of fishing capacity management requires strong commitment by the countries involved in tuna fishing, which would share information on tuna vessels and establish mechanisms to detect and to prevent, if possible, new entries to tuna fishing activities, except as replacements for vessels that were no longer fishing for tunas.

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[1] Not reproduced in these Proceedings.

Paper-specific discussion: It was noted that the information on vessels that is available to the public is inadequate, and the importance of reliable fleet statistics was re-emphasized. It was further noted that monitoring of vessels on the high seas is of great interest to many different fisheries bodies, and that attempts are underway to establish mechanisms to do that. The importance of coordination between FAO and the regional fisheries management organizations (RFMOs) for development of mechanisms acceptable to both the fishing industry and conservation groups was expressed.

Paper 7: Measurement of the global fishing capacity of large-scale tuna purse seiners[2]

Dr Majkowski mentioned that at the second meeting of the Technical Advisory Committee it was recommended that the estimates of the total number of large-scale purse seiners and their total carrying capacity that were obtained for 2000 by Dr Joseph (2003)[3] be updated. This proved to be more difficult than anticipated because there was no system for routinely collecting information with which to obtain such estimates. Therefore, the estimates for different years are not necessarily comparable. He described the sources of information for the update:

- Atlantic Ocean: mostly information from governmental organizations of France, Spain and Venezuela and, to a lesser extent, the register of tuna vessels of the International Commission for the Conservation of Atlantic Tunas (ICCAT);
- Indian and eastern Pacific Oceans: registers of tuna vessels of the Indian Ocean Tuna Commission (IOTC) and the Inter-American Tropical Tuna Commission (IATTC);
- western and central Pacific Ocean: a study carried out by Gillett and Lewis (2003)[4].

Then, Dr Majkowski presented updates of the estimates of the number of large-scale purse seiners and their carrying capacity, explaining that the Project could not obtain information on purse seiners registered in Ghana. Possibly because of that, the estimated number of purse seiners in the Atlantic Ocean for 2004 was less than that for 2000. For the Indian and eastern Pacific Oceans, the numbers of purse seiners in 2000 and 2004 were very similar. The numbers of purse seiners in the western and central Pacific Ocean were less in 2004 than in 2000, possibly because purse seiners registered in coastal countries of the region that operate only in the exclusive economic zones (EEZs) of those countries were not included in the 2004 data. In addition, the estimates of the carrying capacities of the fleets operating in all oceans appeared to be less in 2004 than in 2000, possibly due to the use of a factor for converting well volume to carrying capacity that was too low. Dr Majkowski concluded that the differences between the estimates obtained for 2000 and 2004 may be indicative of difficulties in estimating carrying capacities, rather than of changes in total capacities.

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[2] Not reproduced in these Proceedings.

[3] Joseph, J. 2003. Managing fishing capacity of the world tuna fleet. *FAO Fisheries Circular*. No. 982: 67 pp. Rome.

[4] Gillett, R & Lewis, A. 2003. A survey of purse-seine fishing capacity in the western and central Pacific Ocean, 1988 to 2003. Gillett, Preston and Associates Inc.

Paper-specific discussion: It was pointed out that the vessel registration data would be useless unless registration was mandatory and utilized to control fishing capacity, which also emphasized the need to bring all data collected by various organizations into a global database. Clarification was sought on several existing conversion factors from tonnes to cubic metres, and it was explained that the factor of 1.17 (tonnes x 1.17 = cubic metres) was originally developed from U.S. shipyard data about 20 years ago, and that more recent information indicated that a higher factor, perhaps 1.4, would be more appropriate for the eastern Pacific Ocean. With respect to the problems in obtaining registration data for small vessels, it was noted that only a few of these operated only within the EEZs of the countries in which they were registered, and that when small vessels operated in the EEZs of other countries information on them was generally provided to those countries. It was affirmed that this problem was most prevalent in the Philippines and Indonesia.

Paper 8: Measuring fishing capacity in tuna fisheries: data envelopment analysis, industry surveys and data collection

Dr Reid provided an overview of data envelopment analysis (DEA) and data requirements for conducting it. He stated that there must be at least some degree of disaggregation from the fishery level on fixed inputs (vessel characteristics) and outputs (catches) and that it must be possible to link these data. He noted that it is necessary, in addition, to have data relating to variable inputs to account for differences in the skills of the vessel captains. Also, estimates of stock abundance and the effects of environmental conditions, or proxies for these, are required if these are to be incorporated into the analysis.

Dr Reid then presented an overview of the data available for the industrial purse-seine, longline and pole-and-line fleets. A reasonable set of fixed input data (vessel characteristics) could be obtained for the large-scale purse-seine, longline and pole-and-line fleets and, in some cases, for smaller vessels. However, it was noted that, aside from the purse-seine fisheries of the eastern Pacific Ocean (EPO) and the western and central Pacific Ocean (WCPO), it was not possible to obtain and link vessel characteristics and catch and effort data throughout the operational ranges of the vessels. He then noted that the crux of the problem that is faced in trying to conduct DEA at a level of disaggregation for which useful results can be obtained is associating the input data with variable input (effort) and output (catch) data at anything but a fishery level, and that the problem is often not the availability of fixed input data, but the availability of the data in a form appropriate for DEA.

Paper-specific discussion: The issue of the level of aggregation at which DEA could best be conducted was discussed. It was suggested that the DEAs that were conducted for the WCPO and EPO purse-seine fisheries, using the most disaggregated data, be conducted with more highly aggregated data, and the results compared.

The issue of stock abundance at potential estimated catch levels was also discussed. It was noted that the DEA previously undertaken and reported to the second meeting of the Technical Advisory Committee used estimated biomass as an exogenous variable to attempt to account for fluctuations in stock levels among fisheries. It was also noted that the analysis was perhaps best viewed from the perspective of what level of reduction was required to ensure that a given target catch was not exceeded.

The participants agreed that the Workshop Statement should encourage all members of the RFMOs to collect and report data to the RFMOs that would permit vessel characteristics, effort and catch data to be linked at the operational level necessary for analyses of fishing capacity.

It was noted that, while it is likely to be technically feasible to undertake industrial surveys of capacity in tuna fisheries, given that capacity surveys are undertaken in many countries covering a wide range of industries, there were likely to be issues relating to funding, the multi-jurisdictional nature of the fisheries and possibly other issues that should be considered. A pilot survey might be conducted before undertaking a full-scale survey.

Paper 9: Assessing capacity in the tuna fishery with desirable and undesirable outputs

Dr Squires' presentation pointed out that fisheries management increasingly emphasizes reductions in undesirable outputs, such as bycatches of marine mammals, sea birds, sea turtles, and unmarketable fishes, including juveniles of target species. If managers desire estimates of capacity conditional on recognizing that the bycatches should be reduced, the conventional output-oriented DEA approach yields greater estimates of capacity than do DEA procedures that incorporate reduction in undesirable outputs. An empirical analysis, using data from 251 pelagic longline sets conducted by 12 US vessels in the US Northeast Distant Water area, demonstrated this point. The desirable outputs were swordfish, albacore, yellowfin tuna, bigeye tuna, bluefin tuna, and sharks, and the undesirable output was sea turtles.

Paper-specific discussion: The possibility of using DEA to address issues relating to the simultaneous catch of bigeye (or other fully-exploited species) and skipjack (or other species that are not fully exploited) was discussed, and it was noted that analysis of such issues could possibly be undertaken within the framework presented in the paper.

General discussion

There was some discussion on the relative benefits of moving toward a bio-economic model that is more complex than DEA to incorporate impact by stock level to frontier, but it was noted that that the bio-economic model had its own shortcomings. The participants were reminded that DEA was selected because it is simple, quick and consistent with economic theory and with the way that governments actually consider capacity and capacity utilization. It was pointed that the objective should be to reduce the fishing capacities to levels commensurate with the stock management objectives. It was suggested that analyses be conducted to assess the tradeoffs between data requirements and the reliability of optimal capacity estimates. The Workshop agreed that a common minimum standard of data collection should be established to ensure the availability of data for DEA, with the understandings that this standard should not prevent any organization from collecting more detailed data.

9. REVIEW OF FACTORS AFFECTING FISHING CAPACITY THAT COULD BE REGULATED BY FISHERIES AUTHORITIES

Paper 10: Factors affecting recent development in tuna longline fishing capacity and possible options for management of longline capacity (Part I)

Dr Miyake presented a follow-up of his paper[5] presented at the second Technical Advisory Committee meeting. He summarized the recent developments that might be affecting the fishing capacity of large-scale (overall length greater than 24 m) longliners. The number of large-scale longliners has declined due to effort for capacity management by governments and industry organizations and economic reasons, including competition with smaller longliners and with purse seiners, increasing fuel costs, decreasing prices for tuna, and scarcity of fish. Also, recent changes in market structure, such as establishment, at the ports where sashimi- and steak-grade tuna are landed, of tuna block processing factories and cheaper air-transportation to locations where the fish are consumed, have reduced the prices of longline-caught tunas. On the other hand, bycatch issues might be negatively affecting longline fishing capacity. (This paper is discussed further under Agenda Item 10.)

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[5] Miyake, P.M. 2005. A review of the fishing capacity of the longline fleets of the world. *FAO Fisheries Proceedings* No. 2: 157-170. Rome.

Paper 11: Tuna fishing capacity: perspective of purse-seine fishing industry on factors affecting it and its management (Part I)

Dr Morón discussed some of the factors affecting estimates of purse-seine capacity and some considerations with respect to these elements that a fleet capacity scheme should contain. An initial consideration related to the actual effect that voluntary agreements, such as the FAO International Plan of Action on fleet capacity, indicates that if management is to be effective it must be applied as mandatory agreements negotiated in the regional fishery management organizations (RFMOs). Some examples of the difficulties in estimating catch rates that could lead to problems in estimation of biomass were presented. Also some other factors, such as skill of the vessel captains, which could affect estimates of fishing effort were discussed. Two existing capacity schemes, those of the IATTC and the Palau Arrangement, were discussed with respect to the purse-seine fishery. (This paper is discussed further under Agenda Item 10.)

Paper 12: Productivity growth in natural resource industries and the environment: an application to the Korean tuna purse-seine fleet in the Pacific Ocean

Dr Squires presented a paper in which it was pointed out that measures of multifactor productivity growth in natural resource industries are biased unless the effects of the environment are taken into account. This paper introduced environmental effects into an output-oriented Malmquist index of multifactor productivity growth to evaluate growth in productivity, technology and technical efficiency for Korean purse-seine vessels fishing for tunas in the western and central Pacific Ocean.

10. REVIEW OF EXISTING MEASURES FOR MANAGING TUNA FISHING CAPACITY AND POSSIBLE IDENTIFICATION OF ADDITIONAL OPTIONS FOR SUCH MEASURES IN THE CONTEXT OF THE OUTCOME OF ADDRESSING AGENDA ITEMS 7 TO 9

Paper 13: Relating DEA estimates of capacity to traditional measures of fishing capacity

Dr Squires presented a paper in which it was pointed out that traditional indicators of fishing capacity, such as vessel numbers or measures of vessel size, such as well capacity, length, or gross registered tonnage (GRT) are widely used to monitor fishing capacity and its changes through time. Data envelopment analysis (DEA) measures of fishing capacity estimate potential output or catch, given this capacity base or capital stock, while assuming that variable input use or fishing effort is unconstrained. DEA measures of fishing capacity, while possessing certain theoretical advantages, can be difficult to estimate and interpret because of complexity, missing data, or lack of timeliness. If changes in traditional measures of fishing capacity are similar to changes in DEA-estimated measures of fishing capacity, then the traditional measures can be readily applied with confidence that they are capturing the underlying situation. A preliminary empirical assessment for the US tropical tuna purse-seine fleet in the western and central Pacific Ocean (WCPO) indicates that the traditional measure holds promise to fundamentally track the DEA-estimated measure if assessed for carefully-considered segments of the fleet. Additional research is required, however.

Paper-specific discussion: The idea that changes in capital stock track changes in fishing capacity was tested in this study. The results indicated that there is no clear relationship between vessel size and fishing capacity in a general sense, but at some aggregation levels the results are more promising. The Workshop noted that the use of GRT alone as a measure of capacity did not necessarily take into account the range of important factors that influence the catch rates and catch potentials of the vessels. In the absence of information on the influence of these other factors, use of nominal capacity measures such as GRT, number of vessels, or other similar metrics, alone, appears to be a rather blunt instrument for managing fishing capacity. While output capacity may be used for measurement, management measures will probably address capital stock.

Paper 10: Factors affecting recent development in tuna longline fishing capacity and possible options for management of longline capacity (Part II)

Dr Miyake discussed the latter half of Paper 10, which stated that the recommendations made at the second Technical Advisory Committee meeting should be implemented for all the fleets, including small longliners and purse seiners. Particular concern was expressed regarding small longliners, which have been increasing in numbers in recent years, but for which information is incomplete. It was agreed that data for these vessels should be collected and incorporated into stock assessments. This might be accomplished by decreasing the lower limit for the vessel registries to less than 24 m. At the same time, the coastal states should be assisted in developing systems for obtaining statistics for small longliners and managing their capacity.

Paper-specific discussion: The Workshop endorsed the suggestion that the statistical documents needed for importation of tuna, be expanded to include all tunas, especially fresh bigeye and yellowfin tuna, caught of longline vessels, and emphasized the need for more data from small (less than 24 m) longliners, which would require technical and other assistance to developing countries that have vessels of this type.

Paper 14: Requirements and alternatives for the limitation of fishing capacity in tuna purse-seine fleets

Dr Joseph indicated that governments and the tuna fishing industry have expressed great concern regarding the excess fishing capacity in the world's tuna fleets. This could lead to overfishing of some tuna stocks, such as yellowfin and bigeye, and to harvests of skipjack in excess of demand, resulting in reduced ex-vessel prices. Analyses have shown that the fishing capacity of the world's purse-seine fleet, measured as the ability of a vessel or fleet to catch fish, is greater than that needed to sustain the current levels of harvest. There have been a number of efforts by regional fisheries management organizations to implement measures to limit the capacity of some of the tuna fleets operating in their respective regions, most of which have been based on regional vessel registers and allocation schemes, with mixed results. Under the general idea of moving away from open access to rights-based management systems, two categories of options for managing fishing capacity, particularly for purse-seine fleets, are reviewed:

- those that do not remove incentives for overcapacity including (1) a regional vessel register modeled after that of the IATTC, coupled with vessel buyback options, and (2) licensing schemes, including fractional licenses and the use of auctions for the sale and transfer of licenses; and
- those that remove the incentives for overcapacity, especially individual transferable quotas (ITQs), as a self-regulating measure that assigns individual quotas.

A moratorium on new entrants was proposed as a short-term solution. This will allow the studies of how best to implement rights-based long-term solutions, such as a global vessel register, with provisions for vessel transferability, ITQs, coupled with other controls, and the development of selective fishing methods.

The meeting of Regional Fishery Management Organizations, which will take place in Kobe, Japan, in January 2007 offers an excellent opportunity to address the problem of overcapacity of tuna fleets.

Paper-specific discussion: The discussion centered on fishing rights, the need to address the aspirations of developing coastal states, and some of the associated allocation problems. It was also mentioned that management of longline and purse-seine vessels may require different schemes, since longline vessels move among ocean areas more often than do purse-seine vessels.

The Workshop reviewed alternatives to capacity management of the purse-seine fleet, and considered future directions, with the general idea of moving from an open-access system to a rights-based one. It proposed, as a short-term measure, a moratorium on new entries to the purse-seine fleet (except as replacements for vessels that had left the fishery). This will allow, in the long term, the development of more specific measures, such as a global vessel register and ITQs. The Workshop recognized that a necessary antecedent for rights-based management would be the distribution of the available harvest among participants, and that it would be necessary to establish criteria for that. Establishing criteria for allocations would facilitate cooperative efforts to manage fishing capacity. The Workshop endorsed these recommendations.

Paper 11: Tuna fishing capacity: perspective of the purse-seine fishing industry on factors affecting it and its management (Part II)

Dr Morón presented some general considerations concerning the basic elements that a fleet management scheme should contain. The paper offered views on fleet capacity from the industry perspective. It pointed out the need for stakeholder participation at all stages of the process, the need for limitations for both the purse-seine and the longline fleets, the use of simpler management schemes based on the numbers of vessels (or their total carrying capacity), provisions for vessel transfers to add legal security to the system and linking marketing to management.

Paper-specific discussion: The Workshop agreed that simple measures of capacity would be most useful for management purposes, but acknowledged that such measures alone were not likely to achieve the objectives of the Regional Fishery Management Organizations.

Paper 15: Buybacks in fisheries

Dr Squires' presentation described how buybacks of fishing vessels, licenses or access and other use rights and gear can be key management tools to address overcapacity, overexploitation of fish stocks and distributional issues. Buybacks can also contribute to a transition from an open-access fishery to a more rational one. As a strategic policy tool, buybacks can help restructure relationhips among participants in a fishery, creating positive incentives that reinforce conservation and management objectives. Buybacks, by reducing vessel numbers, increasing profitability, strengthening positive incentives, improving attitudes and lowering exploitation pressures on fish stocks, can also help in the establishment of self-enforcing voluntary agreements among industry participants. Selectively-targeted buybacks can also help conserve ecological public goods, such as species other than tunas, when sets are made on tunas associated with dolphins or floating objects. This paper offered a view of buyback systems as a transition tool toward rights-based management schemes. The review pointed out that some kind of limited-entry system, such as a regional vessel register, must be in place if buybacks are to work efficiently, and discussed some of the details that must be solved in an international setting, such as what to buy back (vessels, rights, or licenses), what to do with vessels removed from the fishery (scrapping, converting to other uses, or transferring to other regions) and discussed some of the supplementary control measures needed.

Paper-specific discussion: The Workshop agreed that buyback programs could provide a basis for transition toward effective rights-based management systems.

TABLE 1

Actions recommended for attaining the long-term objective of instituting rights-based management systems to eliminate overcapacity in tuna fisheries

What to do	Stages in achieving objective		
	Assess current situation	Stabilize in short and medium term	Optimize in long term
Monitor stock status	X	X	X
Monitor fishing capacity	X	X	X
Expand coverage and harmonize regional vessel registers	X	X	X
Expand market monitoring methods	X	X	X
Limit entry by			
Establishing moratoria on capacity		X	
Instituting licensing			X
Establishing a global vessel register			X
Establishing individual transferable quotas and ITEs			X
Voluntary agreements		X	X
Establish allocation criteria		X	X
Monitoring, control and surveillance	X	X	X
Eliminating illegal, unreported and unregulated fishing and encouraging membership in RFMOs		X	X
Buyback programs		X	

General discussion

As a result of the discussions of this section, the Workshop concluded that to have an effective fleet management scheme the first priority should be an immediate stabilization of the world tuna fleet, The scheme would take into consideration the legal security that private operators should have to operate from the different countries participating in the RFMO, facilitating movement of capacity among countries. Compliance would be ensured through application of measures with significant costs to non-compliant parties.

The available evidence indicates that, globally, there is more capacity than needed to harvest most of the stocks of tunas at their maximum sustainable levels. It is the view of the Workshop that institution of effective rights-based management systems would lead to elimination of overcapacity in the tuna-fleets. Full implementation would be a long-term process, involving many complexities in establishing the use rights for the participants in the fisheries. Until such systems have evolved, it is the recommendation of the Workshop that steps be taken to prevent further growth and to reduce global tuna fishing capacity. The steps and subsequent actions that could be taken to realize this objective are summarized in Table 1.

The Workshop recognized that management schemes should make provision for replacement of existing capacity, while ensuring that total fleet capacity does not increase as a result of replacement.

It is important to involve stakeholders, to ensure transparency and to ensure accuracy of the information from which conclusions are drawn. Global coordination is needed to prevent spillover of overcapacity from one region to another.

Complimentary management measures to be used in conjunction with capacity measures could include effort limits, catch limits, time and area closures, conservation incentives and measures to encourage compliance, including, if necessary, trade measures.

11. STATEMENT FROM THE WORKSHOP: DISCUSSION OF CONTENT

The Workshop discussed the content of the Statement, and agreed that it should have a preamble linking it to the previous work of the Technical Advisory Committee. The Workshop further agreed that there should be a section on overcapacity diagnostics, and a list of specific management recommendations.

12. FUTURE RESEARCH RELATED TO THE MANAGEMENT OF TUNA FISHING CAPACITY: FORMULATION OF A PROPOSAL (COMBINED WITH AGENDA ITEM 13)

13. OVERALL DISCUSSION AND RECOMMENDATIONS (COMBINED WITH AGENDA ITEM 12)

FAO indicated that the tasks of the Project's work plan that were of the highest priority were mostly completed, but that there was insufficient funding to undertake other tasks that were held in abeyance until funds became available. The discussion was focused on general needs for additional data and on other technical aspects of the problem of measuring fishing capacity.

In order to improve output-based measures of fishing capacity, more detailed data relating catches to physical measurements, such as numbers of vessels or vessel carrying capacities, is required. Those data that are routinely collected from logbooks and through observer and enforcement programs are, at a minimum, available at national levels and, in some cases, for RFMOs, and these could be made available for research purposes with appropriate arrangements with the owners of the data. At the same time, mandatory data requirements for capacity management should be established in a harmonized way to allow consistent capacity estimates and controls across regions.

In general, data collection and reporting is not a serious problem for industrialized fleet, but the Workshop noted a lack of data for many coastal fisheries with many small vessels that may have large combined capacities. The Workshop agreed that assistance should be provided to those countries in developing and improving their structure and infra-structure required for data collection and controls of capacity management.

Data envelopment analysis (DEA) has been used for estimation of fishing capacity. Many variations of DEA could be used, depending of the quality of the data available and the type of information that is being sought. If the results of the analyses are to be aggregated, the methods and assumptions should be comparable.

The Workshop drew the conclusions and made the recommendations reported under Agenda Item 10 and in the Statement of Agenda Item 11. Furthemore, the Workshop agreed on the following recommendations.

The Workshop noted that all tuna RFMOs have or are developing vessel registers in which vessels are not necessarily identified uniquely and may be reported under different names, and **recommends** that the RFMOs adopt a common database and minimum standards for vessel data and that they combine their individual registers into a common global vessel register.

The Workshop noted that data that can be used for estimating fishing capacity exist for purse-seine and most longline vessels greater than 24 m in length, but was concerned about the paucity of data for other vessels, particularly longline vessels less than 24 m in length, and **recommends** that the states collect input (vessel numbers, characteristics and fishing effort) and output (catch) data that are linked for all parts of the fleet, including an expansion of the statistical document systems to include fresh fish.

During its discussion the Workshop identified the following topics for future research:

- Investigation of changes in fishing power and productivity of fishing vessels over time.
- Studies of methods of fishing directed at one species, particularly skipjack, that minimize the catches of species that are considered to be overfished.
- Further development of methods to estimate fishing capacity based on stock assessment.
- Investigation of the effects of aggregation of data on fishing capacity estimates and the implications for minimum data standards.

- Investigation of the relationships between fishing capacity and the physical characteristics of the vessels.
- Monitoring of socio-economic factors that are directly associated with fishing capacity, including fuel costs, fish prices and diet preferences.

14. STATEMENT FROM THE WORKSHOP: REVIEW OF ITS FIRST DRAFT

The first draft of the Statement was reviewed, and some suggestions were made for changes.

15. OTHER MATTERS

No other matters were discussed.

16. ADOPTION OF THE STATEMENT FROM AND REPORT OF THE WORKSHOP PROVISIONAL LIST OF PAPERS

The Statement in Appendix VI was adopted by the Workshop.

17. ADJOURNMENT

On behalf of FAO and its Project that organized the Workshop, Dr Majkowski thanked all the participants for their valuable technical input to the Workshop. He expressed particular thanks to:

- Dr Robin Allen, Chairman of the Workshop, for very effectively leading the discussions;
- the authors of the papers;
- the rapporteurs;
- Ms Alejandra Ferreira and Ms Mónica Galván for their help during the Workshop.

Dr Majkowski mentioned that FAO and its Project are grateful to all the organizations that provided strong support and substantial contributions to the Workshop. In this respect, he mentioned specifically (1) the IATTC, the host of the Workshop, and (2) the government of Japan, the principal donor to the Workshop.

APPENDIX I

Programme

Background information

Tuna stocks have traditionally been managed on the basis of information from the stock assessments conducted by scientists. As a result of these assessments, desired values of population parameters or their reference points, including fishing mortality, are routinely estimated for each stock.

If the fisheries management is to include fishing capacity, a desired magnitude of or a desired change of fishing capacity must be estimated. This has been done recently for a few tuna fisheries by means of data envelopment analysis (DEA). DEA is used to estimate the output of fishing capacity and capacity utilization. It calculates a frontier or maximum landings curve, as determined by the best-practice vessels, given the state of technology, environment and stocks (fixed inputs), provided that fishing effort (variable input) is fully utilized under normal operating conditions.

DEA has been performed on a few purse-seine fisheries, but not on other important tuna fisheries, such as longline and pole-and-line fisheries operating on the same or other tuna stocks.

DEA, unlike other types of stock assessment, cannot be performed routinely on most stocks because it requires input data that are not presently available for most tuna fisheries. Industry surveys of tuna fishing capacity utilization have not been performed to any significant extent, if at all.

Because the assessment of stock status is routinely carried out for most stocks of the principal market species of tunas, it might be more practical, if feasible, to determine the desired magnitude of or desired change in fishing capacity from information from these assessments, rather than from DEA or industry surveys of tuna fishing capacity utilization. Fishing effort is considered to be proportional to fishing mortality, but the relationship between fishing effort and fishing capacity is more complicated. Because of that, quantitative methods must be developed to estimate the desired magnitude of or the desired change to fishing capacity on the basis of the status of tuna stocks, taking into account the multi-species and multi-gear nature of the tuna fisheries, which significantly complicates analyses and provision of advice for the management of tuna fishing capacity.

Therefore, the second Workshop of the Technical Advisory Committee of the FAO Project on the "Management of Tuna Fishing Capacity: Conservation and Socio-economics", held in Madrid, Spain, on 15-18 March 2004, recommended that the Project, in collaboration with tuna agencies and programs, should organize a Workshop to develop quantitative methods to determine the desired magnitude of or desired change to fishing capacity on the basis of the status of stocks.

Subsequently, as a result of informal discussions among some members of Technical Advisory Committee, it was proposed that the scope of the Workshop be extended as outlined in the Objectives section below.

Subsequently, a preliminary proposal of the Workshop was prepared by the FAO Project and presented and discussed at the fifth Meeting of the Secretariats of Tuna Agencies and Programs in Rome, Italy, on 11 March 2005. The Workshop generally agreed that it would be a good idea to extend studies on fishing capacity to combine economic and biological considerations. They considered that the outcome of the Workshop would be relevant for the work of their organizations and their member countries, rendering technical assistance to their fisheries managers in undertaking decisions on the management of tuna fishing capacity.

Objectives

A. To develop quantitative methods to determine the desired magnitude of or desired change to fishing capacity on the basis of the status of the stocks, taking into account the multispecies and multigear nature of the tuna fisheries;

B. To determine the feasibility of (1) routinely collecting input data for data envelopment analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization;

C. To relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity;

D. To review the factors affecting fishing capacity (numbers of vessels, their physical characteristics, *etc.*) that could be regulated by fisheries authorities;

E. To review the existing measures for managing tuna fishing capacity, and possibly, to identify additional options for such measures in the context of the outcome of addressing Objectives A through D;

F. To prepare a Statement of the participants in the Workshop;

G. To formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and the other organizations participating in the Workshop.

Arrangements for and support to the Workshop

FAO's Project on the Management of Tuna Fishing Capacity is organizing the Workshop, coordinating and contributing to the technical work preparatory to the Workshop. FAO's Regular Programme will also contribute to that work, and some of its experts will participate in the Workshop.

The Inter-American Tropical Tuna Commission (IATTC) in La Jolla, California, USA, will host the Workshop.

Support to the Workshop is being provided by (1) most tuna agencies and programs and (2) some other international and national fisheries organizations, including (3) those of the tuna fishing industry and (4) universities. They include:

- the Forum Fisheries Agency (FFA), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Indian Ocean Tuna Commission (IOTC), the Secretariat of the Pacific Community (SPC);
- the Japan Tuna Fisheries Cooperative Association, the National Marine Fisheries Service (NMFS), the National Research Institute of Far Seas Fisheries (NRIFSF), the World Tuna Purse-Seine Organization (WTPO);
- the College of William and Mary (CWM) and the University of California at San Diego (UCSD).

These organizations are contributing to the technical work preparatory to the Workshop, including the implementation of various studies to be documented in the papers for their presentation at the Workshop. They will also finance the participation of their experts in the Workshop. All the contributions to the Workshop will be fully acknowledged in the Proceedings of the Workshop.

APPENDIX II

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APPENDIX III

Provisional agenda

Registration: 8:30 to 9:30 on Monday, 8 May 2006
Sessions: 9:00 (with the exception of the first day—see below) to 17:00
Coffee breaks: 10:30 to 10:45 and 15:15 to 15:30
Lunch breaks: 12:15 to 13:45
Presentation of papers: 20 min. each, followed by 10-min. question-and answer-session with a 90-min. overall discussion at the end of each substantive Agenda Item

Monday, 8 May 2006

1. [9:30] Opening
2. [9:45] Introduction of participants
3. [9:50] Adoption of provisional agenda and of provisional list of papers
4. [9:55] Logistic arrangements for the Workshop
5. [10:05] Statement from and Report of the Workshop: content and logistic arrangements for their preparation
6. [11:00] Overview of the Project and its implementation
7. [11:15] Development of quantitative methods to determine the desired magnitude of or desired change to fishing capacity on the basis of the status of stocks, taking into account the multi-species and multi-gear nature of tuna fisheries

Tuesday, 9 May 2006

8. [9:00] Feasibility of (1) routinely collecting input data for the data envelopment analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization
9. [13:45] Review of factors affecting fishing capacity (number of vessels, their physical characteristics, etc.) that could be regulated by fisheries authorities

Wednesday, 10 May 2006

10. [9:00] Review of existing measures for managing tuna fishing capacity and possibly, identification of additional options for such measures in the context of the outcome of addressing Agenda Items 7 to 9
11. [11:15] Statement from the Workshop: discussion of content
    Note: After the completion of Agenda Item 11, the first draft of the Statement will be prepared, probably by a small group of participants, which will be identified at the Workshop for its presentation on the next day (see Agenda Item 14).

Thursday, 11 May 2006

12. [9:00] Future research related to the management of tuna fishing capacity: formulation of proposals
13. [11:15] Overall discussion and recommendations
14. [15:30] Statement from the Workshop: review of its first draft
    Note: After the completion of Agenda Item 14, the first draft of the Statement will be revised for its adoption on the next day (see Agenda Item 16).
15. [16:45] Other matters

Friday, 12 May 2006

16. [9:00] Adoption of the Statement from and Report of the Workshop Provisional List of Papers
17. [11:00] Adjournment

APPENDIX IV

List of papers

P1 Overview of the FAO Project on the Management of Tuna Fishing Capacity and its implementation, by Jacek Majkowski (FAO)

P2 Estimated target fleet capacity for the tuna fleet in the eastern Pacific Ocean, based on stock assessments of target species, by Pablo Arenas (IATTC)

P3 Estimates of large-scale purse-seine, baitboat and longline fishing capacity in the Atlantic: an analysis based on a stock assessment of bigeye tuna, by Victor Restrepo (ICCAT)

P4 A case study of the impact of recent management measures on the overall fishing capacity and fishing effort of the United States longline fleet that fishes in the North Atlantic Ocean, by Gerald P. Scott (NMFS) and Guillermo Díaz (NMFS)

P5 Estimates of large-scale purse-seine and longline fishing capacity in the western and central Pacific Ocean based on stock assessments of target species, by John Hampton (SPC)

P6 Review of existing information and its potential use for analyses and management of fishing capacity, by Sachiko Tsuji (FAO)

P7 Measurement of the global fishing capacity of large-scale tuna purse seiners, by Jacek Majkowski (FAO)

P8 Measuring fishing capacity in tuna fisheries: data envelopment analysis, industry surveys and data collection by Chris Reid (FFA) and Dale Squires (NMFS)

P9 Assessing capacity of the United States Northwest Atlantic pelagic longline fishery for highly migratory species with undesirable outputs, by Tara Scott (CWM), James Kirkley (CWM), Ronald Rinaldo (NMFS) and Dale Squires (NMFS)

P10 Factors affecting recent development in tuna longline fishing capacity and possible options for management of longline capacity by Makoto Peter Miyake (Tuna Japan)

P11 Tuna fishing capacity: perspective of the purse-seine fishing industry on factors affecting it and its management, by Julio Morón (OPAGAC)

P12 Productivity growth in natural resource industries and the environment: an application to the Korean tuna purse-seine fleet in the Pacific Ocean, by Dale Squires (NMFS), Christopher Reid (FFA) and Yongil Jeon (Central Michigan University)

P13 Relating DEA estimates of capacity utilization to traditional measures of fishing capacity by Dale Squires (NMFS), James Kirkley (CWM), James Joseph, Theodore Groves (UCSD) and Chris Reid (FFA)

P14 Requirements and alternatives for the limitation of fishing capacity in tuna purse-seine fleets, by James Joseph, Dale Squires(NMFS), William Bayliff (IATTC) and Theodore Groves (UCSD)

P15 Buybacks in fisheries, by Dale Squires (NMFS), James Joseph and Theodore Groves (UCSD)

Information documents

I1 Report of the Second Meeting of the Technical Advisory Committee (TAC) GCP/INT/851/JPN, Madrid, Spain, 15-18 March 2004

12 Bayliff, W.H.; Leiva Moreno, J.I. de; Majkowski, J. (eds.) Second Meeting of the Technical Advisory Committee of the FAO Project "Management of Tuna Fishing Capacity: Conservation and Socio-economics". Madrid, Spain, 15-18 March 2004. FAO Fisheries Proceedings No. 2. Rome, FAO. 2005. 336p.

13 Carocci, F. and Majkowski, J. Tuna catch statistics—FAO collections: status and issues

APPENDIX V

Glossary of terms

Capacity

Capacity refers to the potential to catch fish. Capacity and capacity utilization are short-run concepts, for which at least one input is fixed, especially the capital stock, given the state of technology, the resource stocks and environmental conditions. Capacity has often been indexed by a measure of the capacity base or capital stock, such as an indicator of vessel size (e.g. carrying capacity, length or gross registered tonnage). Capacity has also been indicated by central governments and in the economic literature by a measure of potential output, i.e. by capacity output.

Capacity output (Output capacity)

Capacity output is a potential output, and one of the widely used indicators of capacity. Capacity output can be purged of technical inefficiency (a measure of fishing skill), since technical inefficiency (i.e. fishing skill) is unlikely to vary over the short run. The remaining reason for not producing at full capacity, i.e. capacity utilization not equal to1, comes from not using all of the available fishing effort (variable inputs), given the fixed inputs, state of technology, environmental conditions and the resource stock.

Capacity utilization

Capacity utilization is the ratio of actual output (catch, landings) to some measure of potential output (capacity output) for a given fleet and biomass level. It is a short-run concept.

Capital

Capital is any previously produced input or asset of a vessel or any other producer. As such, capital is a stock. In practice, capital can be thought of as "real" assets, such as vessels, gear and equipment.

Capital utilization

Capital utilization is defined as the ratio of the desired stock of capital to the actual stock of capital and measures the utilization of a given capital stock. Capital utilization differs from capacity utilization. Capacity utilization refers to the utilization of all inputs, rather than not just the stock of capital.

Carrying capacity

Carrying capacity is measured for most tuna fishing vessels as the tonnage of fish that can be stored on the vessel when it is fully loaded or the storage area, measured in cubic metres. Carrying capacity is sometimes used as an indicator of the fishing capacity of a vessel or fleet, and is assumed to be related to the ability of a vessel to catch fish under normal operating conditions.

Data envelopment analysis (DEA)

DEA is a "frontier"-based method: the outputs of individual vessels in the fleet are compared, with the "best" set of vessels, used as a benchmark. The "best" vessels are those that have the greatest levels of output per unit of input. These vessels determine the "frontier". DEA is a non-parametric technique, solved using a linear programming model, so it cannot deal directly with random error (e.g. "luck" in terms of catch).

Excess capacity

Excess capacity is the difference between fishing capacity and actual harvest.

Fishing capacity

Fishing capacity is the amount of fish (or fishing effort) that can be produced over a period of time (e.g. a year or a fishing season) by a vessel or a fleet if fully utilized and for a given resource condition. Full utilization, in this context, means normal, but unrestricted, use, rather than some physical or engineering maximum.

Fishing power

Fishing power refers to relative efficiency among gear and vessel types, based on total annual or seasonal catches. Following Gulland (1986)[1], fishing power can be defined as the product of the area of influence of the gear during a unit of operation and the efficiency of the gear during that operation. Because the concept of absolute fishing power is difficult to measure, the concept of relative fishing power is frequently used. Relative fishing power is defined by Beverton and Holt (1957, pp. 172-173)[2] as, "The ratio of the catch per unit fishing time of a vessel to that of another taken as standard and fishing on the same density of fish on the same type of ground." More operationally, fishing power of any vessel can be defined by reference to a standard vessel, whose fishing power is expected to be constant, by comparing the catches of these vessels when fishing at the same time and place.

Fixed input (Fixed factor)

Fixed inputs are inputs whose levels are held fixed in a time period; their services do not vary with the amount of the output produced. Examples include the vessel, engine and some gear and equipment.

Inputs (Factors of production)

Inputs are any good or service that contribute to the production of an output. Inputs typically include capital, labour, energy and materials.

Investment

Investment refers to changes in the capital stock in a given time period. **Gross investment** is the sum of replacement investment and net investment in a time period. **Replacement investment** is the amount of investment in a time period designed merely to replace the amount of capital that has deteriorated or has been converted to other uses or scrapped. **Net investment** refers to the net increment to the capital stock since the last time period, and equals total investment minus replacement investment.

Long run

Long run refers to the time period in which all inputs can be adjusted. For example, the capital input (the vessel) is generally fixed in the short term, while fishing effort can be varied. In the long term, fishers can change their vessels or alter their fishing activities. In the short run, capital and equipment are generally viewed as fixed inputs; that is, they cannot be increased or decreased. For example, a vessel size cannot be changed in the short-run. Over the long run, however, capital and equipment may be viewed as variable inputs. They can be changed. A vessel owner, for example, can modify a vessel or replace it with a larger or smaller one.

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[1] Gulland, J.A. 1983. *Fish Stock Assessment: a Manual of Basic Methods.* New York, FAO/Wiley Series on Food and Agriculture, Vol. 1: 223 pp.

[2] Beverton, R.J.H., & Holt, S. J. 1957. On the dynamics of exploited fish populations. *Minis. Agri. Fish. Food, Fish. Inves.*, Ser. 2, 19: 533 pp.

Overcapacity

Overcapacity can be considered the generic term for excessive levels of capacity in the longer term, and it relates to some long-term desirable level of capacity (the target capacity). This may be either some long-term target sustainable yield, or some long-term target level of capital employed in the fishery.

Overcapitalization

Overcapitalization refers to an actual capital stock that is in excess of that optimum capital stock required to produce some optimum output level. Overcapitalization occurs through over-investment in capital.

Overcapacity and overcapitalization

Overcapitalization refers to only the capital stock, whereas overcapacity is more all-encompasing in that it includes all fixed inputs (capital such as the vessel and engine) and variable inputs to harvest operations, such as labour (crew), fuel, ice and other relevant variables.

Production frontier

The production frontier represents the maximum output attainable from each input level, given the current state of technology in the fishery, environmental conditions and resource stocks. The term **best-practice production frontier** refers to the production frontier established by the vessels with the highest production performances, as opposed to an engineering concept in which the production frontier is established solely on engineering or technical grounds.

Peak-to-peak method

The peak-to-peak method measures capacity by measuring the observed relationship between catch and fleet size. Periods of greatest catch, given the harvesting technology, capital stock, resource stock and state of technology, provide measures of full capacity. The approach is called the peak-to-peak method because the periods of full utilization, called peaks, are used as the primary reference points for the capacity index. Changes in peak catch rates are assumed to be due tochanges in technology or resource stock conditions.

Short run

Short run refers to the time period in which at least one input is held fixed, *i.e.* there is a fixed input. For example, in the case of fisheries, the capital input (the vessel) is generally fixed in the short term, while fishing effort can be varied. In the long term, fishers can change their vessels or alter their fishing activities.

State of technology

State of technology refers to the current, existing state of technical knowledge as to how goods and services can be produced. **Changes in the state of technology** refer to **technical change** or **technical progress**.

Target capacity

Target fishing capacity is the maximum amount of fish over a period of time (year, season) that can be fully utilized while satisfying fishery management objectives designed to ensure sustainable fisheries, *i.e.* $Y_T = Y(E_T, S)$, where Y_T is the target yield or catch, E_T is the target effort generated by a fully-utilized fleet, and S is the stock size (biomass).

Technical efficiency

Technical efficiency (TE) occurs when the maximum amount of an output is produced for a given set of inputs (output-oriented technical efficiency) or when the minimum amount of inputs are required to produce a given output level (input-oriented technical efficiency). TE ranges between 0 and 1. TE is 1 when a vessel is full technically efficiency, so that it cannot catch any more fish with the available inputs (fishing effort and vessel). TE <1 when a vessel is not fully technically efficient, *i.e.* when it is technically inefficient. A vessel is inefficient because technically it could increase its catch to the level of the best-practice production frontier without requiring more input.

Total factor productivity (Multi-factor productivity)

Productivity of a vessel is the ratio of the output(s) (Y) it produces to the input(s) (X) it uses, *i.e.* productivity = outputs/inputs or Y/X. **Total factor productivity** refers to a productivity measure involving all inputs. In the presence of multiple outputs and multiple inputs, total factor productivity may be defined as a ratio of aggregate output produced relative to aggregate input used. **Partial productivity** refers to a productivity measure that does not involve all inputs, and usually refers to a productivity measure involving only one input. Examples of partial productivity measures are output per worker, output per hectare or catch per unit of effort. **Productivity growth** refers to an increase in productivity over time, *i.e.* where the ratio of output to input increases over time or $\dot{Y}/Y - \dot{X}/X$.

Variable inputs (Variable factors)

Variable inputs are inputs that can be freely varied in a time period, and hence vary according to the amount of output produced. Examples of variable inputs in fisheries include fuel, bait, light sticks, sometimes crew and some gear and equipment.

APPENDIX VI

Statement from the Workshop

Statement from the Workshop on the Management of Tuna Fishing Capacity La Jolla, California, USA, 8-12 May 2006

This Workshop is the third meeting convened by the FAO Project created in response to concerns about overcapacity in tuna fisheries on a global scale. The third meeting recalled and built on the conclusions and recommendations from the two previous meetings.

The available evidence indicates that globally there is more capacity than needed to achieve the management objectives for most tuna stocks. Notwithstanding management measures implemented by Regional Fishery Management Organizations (RFMOs), overcapacity has already led to overexploitation of some tuna stocks, and it is likely to lead to overexploitation of other tuna stocks that are close to being fully exploited. This puts tuna stocks and the fisheries for them at a significant risk.

It is the view of the Workshop that effective rights-based management systems will lead to elimination of overcapacity in the tuna fleets. The Workshop recommends that steps, as listed below, be taken to prevent further growth of fishing capacity.

Rights-based management systems allow individual vessel owners to transfer the capacity of their vessels to other countries participating in the RFMO and make provision for the replacement of existing capacity, while ensuring that the total fleet capacity does not increase as a result of replacement. Compliance should be ensured through application of measures with significant cost to non-compliant parties. The Workshop recognizes the importance of involving stakeholders to ensure transparency and to ensure accuracy of the information from which conclusions are drawn. Global coordination is needed to prevent spillover of overcapacity from one region to another.

The Workshop recommends that the management of fishing capacity should include:

1. an immediate moratorium on the entry of additional large-scale vessels;
2. allocation criteria and mechanisms to provide for new participants;
3. participation by all tuna fishing nations and fishing entities in tuna RFMOs;
4. improved monitoring of tuna fishing fleets and their activities, to facilitate control of fishing capacity regionally and globally;
5. collection, by states, fishing entities and RFMOs, of information on activity of vessels that are not currently monitored;
6. limited entry to regional registers of vessels that fish for tunas that, in combination, provide a global register;
7. use of buybacks or similar incentives to reduce overcapacity;
8. assurance of the rights of participants in the fishery and incentives for their contributions to conservation and management; and
9. a high level of transparency by including participation of stakeholders in the management at every step.

The Workshop recommends that this Statement be presented to the meeting of tuna RFMOs and their Members to be held in Kobe, Japan, in January 2007, and offers this Statement to the RFMOs and their Members for their consideration.

Papers presented at the Workshop

Overview of the FAO Project on the Management of Tuna Fishing Capacity and its implementation

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ABSTRACT

The general objective of the Project has been to improve the management of tuna fisheries on a global scale, and specifically to:

- provide technical information necessary for achieving its objectives and
- identify, consider and resolve technical problems associated with the management of tuna fishing capacity on a global scale, taking into account conservation and socio-economic issues. In the implementation of the Project, FAO collaborated with tuna fishery bodies all over the world, INFOFISH (a source of marketing support for fish producers and exporters in the Asia-Pacific region), the Organization for Promotion of Responsible Tuna Fisheries (OPRT), the Secretariat of the Pacific Community (SPC), the Forum Fisheries Agency (FFA) and the World Tuna Purse Seine Organisation (WTPO), utilising their expertise, data and other information of relevance to the Project.

The Project's duration has been four years. Its activities have consisted of:

- technical studies,
- meetings of the Project's Technical Advisory Committee (TAC, plus some other meetings to review and integrate the results of the technical work and to formulate conclusions and recommendations and
- the dissemination of these findings.

The subjects of the studies have been: (1) tuna fisheries and resources, (2) estimation of tuna fishing capacity, (3) the tuna industry and (4) optimum tuna fishing capacity, management options and implications.

1. BACKGROUND INFORMATION

Tuna and tuna-like species are very important economically, and are a significant source of food for both developing and developed countries world-wide. The "principal market species", skipjack *Katsumonus pelamis*, yellowfin *Thunnus albacares*, bigeye *T. obesus*, albacore *T. alalunga*, Atlantic bluefin *T. thynnus*, Pacific bluefin *T. orientalis* and southern bluefin *T. maccoyii*, are most important among the tuna and tuna-like species in terms of both weight and value. These species are the subject of the Project's activities. For convenience, they will be referred to in this paper simply as "tuna" or "tunas".

The present tuna fishing capacity is excessive in respect to both the tuna resources and the demand for tuna products. This excess has led to an overexploitation, or even depletion, of some tuna stocks. In the recent past, prices for unprocessed tuna were reduced to the extent that it was no longer profitable to fish for some tuna species. The problem became so critical that the owners of tuna purse seiners tried to resolve it independently of governments and international organizations by forming a global organization, the World Tuna Purse-seine Organization (WTPO), to limit, as necessary, the fishing effort generated by their vessels. The number of longliners has already been reduced in some countries, and there are plans to reduce it further. However, these voluntary actions are unlikely to be sufficient in the long-term.

In response to:

- FAO's International Plan of Action (IPOA) for the Management of Fishing Capacity and
- the status of tuna resources and fishing capacity in each ocean,

some tuna fishery bodies have already started to manage tuna fishing capacity in their areas of competence, and some others are considering it. The technical problems associated with the management of tuna fishing capacity are similar in all oceans. They are multidisciplinary, and involve conservation, socio-economic and technological issues (*e.g.* the effect of technological improvements on (1) fishing capacity, (2) effective fishing effort, mortality and catches, (3) resources, (4) prices of tuna products, which are determined also by the demand for tuna products competing with other food products and (5) the profitability of tuna fishing and processing). Presently, few, if any, of the regional fishery management organizations (RFMOs) that are involved in tuna management have the economic expertise required to address and resolve theses problems, so they must rely on the expertise of their member countries.

Tuna are fished, traded, processed and consumed almost globally. Large tuna vessels are capable of quickly moving from one ocean to another, and vessels registered in coastal countries of one ocean frequently fish in another ocean in response to changes in the apparent abundance of fish or in economic conditions. Such movements are likely to continue in the future. Transfers from one region to another make the management of fishing capacity on a regional scale more difficult than it would be otherwise. Also, substantial illegal, unregulated and uncontrolled (IUU) fishing, which occurs in all oceans and which is carried out by vessels that may transfer from one ocean to another, significantly complicates management.

For the reasons mentioned above, it is necessary to analyse, consider and discuss the technical problems associated with the management of tuna fishing capacity on a global scale in a multi-disciplinary context. This will:

- make it possible to address adequately the technical problems through intensive research into them, while avoiding the duplication of research effort;
- enhance the management of tuna fishing capacity by individual tuna RFMOs in the areas of their competence and at national levels; and
- possibly lead to some global recommendations and/or decisions to be undertaken, making the management of tuna fishing capacity more effective at the global, regional and national levels.

Therefore, at the 24th session of FAO's Committee on Fisheries, held on 26 February-2 March 2001, some countries requested FAO's assistance in addressing the problem of tuna fishing overcapacity. It recognized FAO's global multidisciplinary expertise and its role associated with fishery resources, fishing, processing and trade and its support of developing countries. It further recognized that some of these countries might need this support to participate actively in international discussions on the establishment of international and national regimes for the management of tuna fishing capacity.Accordingly, FAO has formulated a Project on the Management of Tuna Fishing Capacity: Conservation and Socio-economics, and Japan has provided funds for its implementation.

2. OBJECTIVE OF THE PROJECT

The general objective of the Project is to improve the management of tuna fisheries on a global scale. Its specific objectives are to:

- provide technical information necessary for and
- identify, consider and resolve technical problems associated with the management of tuna fishing capacity on a global scale,

taking into account conservation and socio-economic issues.

3. IMPLEMENTATION

3.1 Collaboration

To facilitate the execution of the Project, FAO has created its Task Force (TF) for the execution of the Project. Its members, who were nominated by FAO's Services and Units involved in the formulation and execution of the Project, are listed below.

- FAO Fisheries Department (FI)
  - Resources Service (FIRM)
    - Marine Dr Jacek Majkowski (Coordinator), Fishery Resources Officer
    - Ms Dora Blessich and Mr Kyriakos Kourkoliotis, Project Analysts
  - Fishery Information, Data and Statistics Unit (FIDI): Ms Adele Crispoldi and Dr Sachiko Tsuji, Senior Fishery Statisticians
  - Fish Utilization and Marketing Service (FIIU): Ms Helga Josupeit, Fishery Industry Officer
  - Development Planning Service (FIPP): Dr Rebecca Metzner, Fishery Analyst (Fishing Capacity)
  - Fishing Technology Service (FIIT)
    - Messrs Joel Prado, Andy Smith and Thomas Moth-Poulsen, Fishery Industry Officers
- Technical Cooperation Department (TC)
  - Policy Assistance Division (TCA), Field Programme Development Programme (TCAP): Mr Uchimura Motomu and Mr Kazumasa Watanabe, Programme Analysts

The Marine Resources Service (FIRM) of the FAO Fisheries Department (FI) leads and coordinates the execution of the Project. Also, the other above-listed services and units of the same department are responsible for the various activities of the Project.

Considering the Project's objectives, FAO would like to implement the Project in a way mutually beneficial to all involved in, dependent on and/or affected by tuna fishing. Fully recognizing the responsibilities and achievements of the various organizations involved in tuna fishing and their members, FAO would like to collaborate with them, utilizing their expertise, data and other information relevant to the Project that they regard as appropriate. These organizations include the tuna RFMOs, INFOFISH, the Organization for Promotion of Responsible Tuna Fisheries (OPRT), the Secretariat of the Pacific Community (SPC), the Forum Fisheries Agency (FFA) and the World Tuna Purse Seine Organization (WTPO).

Therefore, the Project has created a Technical Advisory Committee (TAC) composed of technical experts affiliated with and/or familiar with the above-mentioned organizations, so, in their personal capacity, they will:

- foster the collaboration of the organizations and their member countries with the Project and
- provide technical advice on the best ways to implement the Project.

The TAC's assistance in the Project's implementation includes:

- provision of technical advice on:
  - access to data and other information required by the Project;
  - selection of methods to be used in the Project's analyses and studies; and

  - identification of consultants and contractors for these analyses and studies, and
- evaluation of the technical work done by the consultants and contractors.

The Members of TAC are listed below.

- Dr Robin Allen, Director, Inter-American Tropical Tuna Commission (IATTC)
- Mr Alejandro Anganuzzi, Secretary, Indian Ocean Tuna Commission (IOTC)
- Dr John Annala, Chair, Stock Assessment Group (SAG), Commission for the Conservation of Southern Bluefin Tuna (CCSBT)
- Dr John Hampton, Manager, Oceanic Fisheries Programme (OFP), Secretariat of the Pacific Community (SPC)
- Dr James Joseph, Consultant
- Dr Peter Miyake, Scientific Advisor, Japan Tuna Fisheries Co-operative Association
- Dr Julio Morón, Assistant Director, Organización de Productores Asociados de Grandes Atuneros Congeladores (OPAGAC) and, till May 2003, Secretary, World Tuna Purse Seine Organization (WTPO)
- Dr Chris Reid, Market Advisor, Forum Fisheries Agency (FFA)
- Dr Victor Restrepo, Assistant Executive Secretary, International Commission for the Conservation of Atlantic Tuna (ICCAT)
- Dr Suba Subasinnghe, Director, INFOFISH
- Dr Naozumi Miyabe, Director, Temperate Tuna Resources Division, and *Dr Ziro Suzuki*, Director, Pelagic Fish Resources Division, National Research Institute of Far Seas Fisheries (NRIFSF)

3.2 Activities

The Project's duration is four years. Its activities consist of:

- technical work;
- meetings of the TAC, and some other meetings to review and integrate the results of the technical work and to formulate conclusions and recommendations; and
- dissemination of these findings.

This work includes:

- collation of data and other information relevant to the management of tuna fishing capacity;
- analyses of these data and information and of other relevant studies; and
- identification of future needs for additional technical work required for better management of tuna fishing capacity.

The analyses and other studies consist of:

- (A1) review of tuna resources and fisheries (the leading FAO Service(s): FIRM with assistance from FIDI),
- (A2) estimation of tuna fishing capacity (the leading FAO Service(s): FIDI/ FIIT with assistance from FIPP and FIRM),
- (A3) determination of demand for tuna raw materials and products (the leading FAO Service(s): FIIU),
- (A4) review of the socio-economic importance and profitability of the tuna industry (the leading FAO Service(s): FIIU/FIIU with assistance from FIIT and FIDI) and
- (A5) determination of options for the fisheries management, particularly that of fishing capacity (the leading FAO Service(s): FIPP/FIRM, with assistance from all other Services of FI).

In the process of their refinements, Studies A3 and A4 were combined into a single Study (A3/A4), for which the FIIU is responsible. The revised titles of the Studies are given below.

- (A1) Tuna fisheries and resources.
- (A2) Estimation of tuna fishing capacity.

- (A3/4) Tuna fishing industry.
- (A5) Optimum tuna fishing capacity, management options and implications of these.

3.3 Studies and related meetings

In mid-January 2003, proposals for the Studies were sent to the members of the TAC for their preliminary review. In response to suggestions for improvements and other comments from the TAC, the proposals for the Studies were revised, taking into account these suggestions and comments.

The first meeting of the TAC was held in Rome, Italy, on 26-28 March 2003 to:

- review methods for estimating the fishing capacity and its value from the conservation and socio-economic view points, and the data requirements;
- determine the applicability of these methods for tunas, particularly in the light of availability of input data for this estimation,
- select the methods most appropriate for use by the Project; and
- finalize the proposal for the Studies to be carried out by the Project, particularly in the context of the methods to be used by the Project for the estimation of tuna fishing capacity, its optimum value and the input data requirements.

In April 2003 after the first meeting of the TAC, the TF finalized the plan of work for implementation of the Studies to be carried out by the Project, taking into account the outcome of the first meeting of the TAC. Subsequently, the Project initiated and carried out the Studies. Emphasis was placed on Studies A1, A2 and A2/3, particularly on the collation and processing of data and other required information.

In March 15-18 2004, the second meeting of the TAC reviewed the Studies carried out by the Project and made recommendations for further work. The outcome of the meeting is documented in:

- the Report of the Second Meeting of the Technical Advisory Committee of the FAO Project "Management of tuna fishing capacity: conservation and socio-economics", Madrid, Spain, 15-18 March 2004,
- the Statement of the Technical Advisory Committee (TAC) for the FAO Project on the Management of Tuna Fishing Capacity: Conservation and Socio-Economics (GCP/INT/851/JPN) and
- the Proceedings of the Second Meeting of the Technical Advisory Committee of the FAO Project "Management of tuna fishing capacity: conservation and socio-economics". Madrid (Spain), 15-18 March 2004. FAO Fisheries Proceedings 2. Eds: W. H. Bayliff, J. I. de Leiva Moreno & J. Majkowski. Rome, 2005.

The Statement of the TAC was presented and discussed at the Technical Consultation to Review Progress and Promote the Full Implementation of the International Plan of Action (IPOA) to Prevent, Deter and Eliminate IUU Fishing and the IPOA for the Management of Fishing Capacity (Rome, Italy, 24-29 June 2004).

The 336-page Proceedings, which was published in 2005, documents the technical outcome of the Project up to the second Meeting of TAC. It provides comprehensive information collated by the Project on the subjects of its Studies. This information is presented in a form of nine substantial papers. They were peer-reviewed and edited before their publication. The information from the papers is summarized and integrated in the 19-page Overview of the Proceedings, including also the major recommendations of the TAC, which were made at its second meeting.

3.4 Major recommendations of TAC at its second meeting

Regarding the collection of data, the TAC recommended that FAO:

- promote efforts to provide external support for the collection of better information on tuna fishing in countries for which small-scale fisheries are a large part of tuna fishing activities;

- encourage countries to collect information on the characteristics and operation of tuna fishing vessels and/or fleets; and
- promote the development of a global record of tuna fishing vessels.

Regarding the management of tuna fishing capacity, the TAC recommended that FAO promote the following actions.

- Imposition of a moratorium on the entry of additional large-scale tuna vessels into the fisheries until an efficient, equitable and transparent system of management of fishing capacity is achieved;
- Establishment of a system for allowing the transfer of fishing capacity within the constraints of the capacity limits that the tuna RFMOs should have;.
- Strengthening of the management of fishing capacity, as recommended above, by any country or fishing entity that has expanded or is expanding its tuna fishing capacity ;
- Collection, by the tuna RFMOs, of information on the numbers, capacities and vessel characteristics for tuna vessels other than purse seiners and longliners (such as pole-and-line vessels and trollers) to determine if excess capacity exists for those fleets;
- Consideration of rights-based management of tuna fisheries, where appropriate, as a long-term solution for the management of excess fishing capacity.
- Establishment of or improvement of monitoring, surveillance and control systems for managing tuna fishing capacity.

In addition to the above general recommendations of the TAC, most of the papers in the Proceedings include specific recommendations as to how to overcome problems encountered during implementation of the studies.

3.5 Workshop

It was also recommended at the second meeting of the TAC that the Project, in collaboration with organizations involved in tuna research and/or management, organize a workshop to develop quantitative methods to determine the desired magnitude of or desired change in fishing capacity on the basis of the status of the stocks. Because the assessment of stock status is routinely carried out for, at least, the principal market species of tunas, the TAC was of the opinion that it might be more practical, if feasible, to determine the desired magnitude of or desired change to fishing capacity on the basis of information from these assessments, rather than from methods such as Data Envelopment Analysis (DEA) or industry surveys of tuna fishing capacity utilization. The tuna fisheries for which DEA has been performed are limited to few purse-seine fisheries, and they do not include other important tuna fisheries, such as the longline and pole-and-line fisheries that often operate on the same stocks. The other problem is that DEA requires input data different from those employed for stock assessments, and those needed for DEAs are not presently available for most tuna fisheries. Industry surveys of tuna fishing capacity utilization have not been performed to any significant extent, if at all.

Subsequently, as a result of informal discussions among some members of the TAC, it was proposed that the scope of the Workshop be extended. A preliminary proposal of the Workshop was prepared by the FAO Project and presented and discussed at the fifth Meeting of the Secretariats of Tuna Agencies and Programs (Rome, Italy, 11 March 2005). It was agreed that the studies on fishing capacity should be extended by combining economic and biological considerations. It was considered that the outcome of the Workshop would be very relevant to the work of their organizations and member countries, assisting their fisheries managers in undertaking decisions on the management of tuna fishing capacity.

Finally, the following objectives have been established for the Workshop.

A. To develop quantitative methods to determine the desired magnitude of or desired change to fishing capacity on the basis of the status of the stocks, taking into account the multi-species and multi-gear nature of the tuna fisheries;
B. To determine the feasibility of (1) routinely collecting input data for Data Envelopment Analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization;
C. To relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity;
D. To review the factors affecting fishing capacity (numbers of vessels, their physical characteristics, *etc.*) that could be regulated by fisheries authorities;
E. To review the existing measures for managing tuna fishing capacity, and possibly, to identify additional options for such measures in the context of the outcome of addressing Objectives A through D;
F. To prepare a Statement of the participants in the Workshop;
G. To formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and the other organizations participating in the Workshop.

Estimated target fleet capacity for the tuna fleet in the eastern Pacific Ocean, based on stock assessments of target species

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ABSTRACT

Tunas are exploited by purse-seine and longline gear in the eastern Pacific Ocean. Purse-seine sets are made on tunas associated with dolphins, tunas associated with floating objects and tunas in unassociated (free-swimming) schools. Sets made on tunas associated with dolphins catch almost entirely yellowfin tuna, and most of these are relatively large. Sets made on tunas associated with floating objects catch mostly skipjack tuna, but also significant amounts of yellowfin and bigeye, most of which are relatively small. Sets made on tunas in unassociated schools catch yellowfin and bigeye of intermediate sizes and skipjack. Longline gear takes large yellowfin, bigeye, albacore and billfishes. The extents to which the various species and the sizes of fish of those species are exploited can be controlled by limiting the effort expended by the various fisheries, but it would be difficult or impossible to exploit all the species at the optimum levels. In general, there is more than enough fishing capacity to fully exploit all the species except skipjack.

1. INTRODUCTION

The first meeting of the Working Group on Limiting the Growth in Capacity of the Purse-Seine Fleet in the Eastern Pacific Ocean (which later became known as the Permanent Working Group on Fleet Capacity) of the IATTC on 3-4 September 1998 formally examined for the first time the question of the "capacity" (meaning fish-carrying capacity) of the purse-seine fleet that fishes for the tunas in the eastern Pacific Ocean (EPO). The document *Considerations Regarding Limiting the Growth in Capacity of the International Tuna Purse-Seine Fleet in the Eastern Pacific Ocean* prepared for that meeting, based mostly on yellowfin tuna (*Thunnus albacares*) stock assessments, concluded that "the current carrying capacity of the fleet, 135,000 [metric] tons, is large enough to generate the amount of fishing effort or mortality required to catch the [average maximum sustainable yield (AMSY)] of yellowfin and the recommended catch of bigeye [*T. obesus*] from the EPO. It is also capable of generating the amount of fishing effort that produced the highest catch of all species combined in the history of the fishery."

As a result of the standardization of well volumes in the Regional Vessel Register of the IATTC, the figure of 135 000 tonnes has been converted into 158 000 m^3, using a multiplier of 1.17, and this rounded figure has been used since 1999 in various documents and resolutions of the IATTC as the maximum target carrying capacity for the purse-seine fleet. While the relationship between carrying capacity in ones and well volume depends on a variety of factors, including the size of fish loaded and the management of the wells, and, in fact, values of 1.4 are more common today, the conversion of 1.17 approximates the United States shipyard calculation of carrying capacity of most of the vessels whose data led to the target of 158 000 m^3.

This target figure of 158 000 m^3 has been reviewed and discussed at meetings of several IATTC working groups and at meetings of the IATTC. For example, at the fourth meeting of the Permanent Working Group on Fleet Capacity on 31 July-2 August 2000, the target capacity was extensively discussed, and alternative target capacities arising from different management regimes were considered. At the sixth meeting of the Permanent Working Group on Fleet Capacity on 7-8 March 2002, the target figure for the purse-seine fleet was again discussed, taking into account especially the developments in the fishery since 1998, particularly the increased catches of skipjack tuna (*Katsuwonus pelamis*). The 69th meeting of the IATTC on 26-28 June 2002, also considered the 158 000 m^3 target capacity of the purse-seine fleet, and endorsed it within the context of the *Resolution on the Capacity of the Tuna Fleet Operating in the Eastern Pacific Ocean (Revised)* adopted at that meeting.

The issue of establishing a target capacity for the longline fleet is a more recent one, and has been considered formally only in the last few assessments. The Permanent Working Group on Fleet Capacity, at its seventh meeting on 20-21 February 2004, requested that the fifth meeting of the Working Group on Stock Assessment on 11-13 May 2004 discuss target capacities for both the purse-seine and longline fleets. The group concluded that the 158 000 m^3 limit seemed appropriate for the purse-seine fleet, from the point of view of optimizing the purse-seine fishery for yellowfin tuna. The group looked also at the suitability of several methods for the control of longline capacity, and concluded that, given management trade-offs and the factors affecting the various tuna fisheries, and considering the potential increase in fishing power of the fleets, the optimal capacity for both components of the tuna fleet would continue to be a moving target. The 72nd IATTC meeting, which took place on 14-18 May 2004, endorsed these views. In summary, a target capacity for the longline fleet has not been established, although effort limits were applied to it during 2004 and 2005.

This document reviews again the question of the target capacity of the tuna purse-seine fleet of the EPO, and offers some views on a possible target capacity for the longline fleet that fishes for tunas and billfishes in the EPO, based mostly on the results of the annual stock assessments carried out by the IATTC staff.

2. FACTORS AFFECTING THE FISHERIES AND MANAGEMENT TRADE-OFFS

The management objectives of the IATTC were established by its 1949 Convention, which states that its principal objective is to "keep the populations of fishes covered by [the] Convention at … levels of abundance which will permit the maximum sustained catch." In the 1949 Convention there is no specific mention of controls for fishing capacity, but it refers to "the effects of [both] natural factors and human activities on the abundance of the populations of fishes supporting all of these fisheries." Various instruments to implement this management goal have been established, especially recently, including establishment of effort or capacity controls for the tuna fleet in the EPO.

The most important management instruments regarding control of tuna fishing capacity in the EPO currently include the *Resolution on the Capacity of the Tuna Fleet Operating in the Eastern Pacific Ocean (Revised)* of June 2002, and the *Plan for Regional Management of Fishing Capacity* of June 2005. Both of these instruments rely upon the vessel register established by the *Resolution on a Regional Vessel Register* of June 2000, and the *Resolution on the Establishment of a List of Longline Fishing Vessels over 24 Meters (LSTLFVs) Authorized to Operate in the Eastern Pacific Ocean* of June 2003.

A new convention, the "Antigua Convention" (open for ratification or accession since 2003) preserves the general objective of maintaining populations of harvested species at levels that can produce the maximum sustainable yields, while introducing more specific provisions regarding the application of the precautionary approach, the possibility of different management objectives for species belonging to the same ecosystem and management references to levels of fishing capacity. Specifically, it refers to "measures to prevent or eliminate ... excess fishing capacity and to ensure that levels of fishing effort do not exceed those commensurate with the sustainable use of the fish stocks covered by this Convention."

Considering management goals and the factors affecting the fishery, it is difficult to establish a size to which the tuna fleet in the EPO should be limited. In the EPO this is complicated by the fact that there are two main types of fishing gear (purse-seine and longline). More complexity is added by the fact that there are three main modes of purse-seine fishing (for unassociated schools of tunas and for tunas associated with dolphins or with floating objects) and that more than one species is frequently caught in a single set.

One possible approach to the establishment of a target capacity would be to keep it at a level that could take the maximum harvest from the fishery, while at the same time ensuring the sustainability of each stock. However, in the multi-species and multi-gear situation of the EPO this objective could be realized only by developing independent species-specific fishing methods and management objectives. The question of an "optimal" fleet capacity depends largely on management objectives.

Given the current mix of fishing gears, set types and species in the fishery, it is logical and prudent to take into account in the establishment of target figure limits the status of the yellowfin stock and the fishery-related connections between the bigeye and skipjack stocks, particularly considering the fact that a large part of the fleet is not targeting yellowfin, and the fact that the catches of skipjack have increased considerably since 1995.

Another important factor, when considering any index leading to tuna fishing capacity control, is the efficiency of the fleet. Because improvements in fishing gear, equipment and techniques generate more effective effort and more fishing mortality, any figure for the "current" optimal fleet capacity must be considered as an upper limit for the desired target. In the case of the purse-seine fisheries, it also depends to a large extent on the size composition of the fleet, as vessels of different capacity classes usually have different fishing efficiencies.

The target fleet capacity will also clearly depend on the productivity of the stocks, which changes over time. In the EPO, regime shifts have occurred at decadal intervals, which might have affected productivity of fish stocks, especially yellowfin tuna, and other components of the ecosystem.

3. TARGET CAPACITY OF THE PURSE-SEINE FLEET

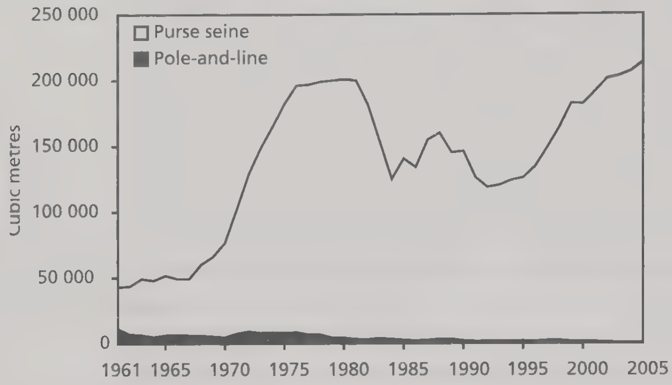
One reason for limiting the capacity of the fleet is that otherwise the catches per vessel will decline, and the economic pressures on individual vessels will be so great that it would be very difficult to sustain an efficient conservation programme. In general, two approaches to establishing a target capacity for the purse-seine fleet could be considered, one based simply on historical fleet capacity and its management repercussions, and the other on data on catches and assesssment indicators, such as catch per unit of effort, yield per recruit and total spawning biomass.

3.1 Fleet carrying capacity and management repercussions

In the EPO, the past management of tuna fisheries can be considered in relation to historical purse-seine tuna fleet carrying capacity. This carrying capacity increased rapidly during the early 1970s, reaching 196,500 m^3 in 1980-1981. It then decreased to 121,650 m^3 in 1984, and remained at an average of about 135 000 m^3 until the mid-1990s, when it began to increase again. The fleet carrying capacity was 182 000 m^3 in 1999, and increased to 213 000 m^3 by the end of 2005 (Figure 1).

FIGURE 1

Carrying capacities of tuna purse-seine and pole-and-line vessels in the eastern Pacific Ocean



Restrictions on fishing for yellowfin in the Commission's Yellowfin Regulatory Area (CYRA), which includes the portion of the EPO that produces most of the catches of tunas, were imposed during the late 1960s, and from 1969 and through 1976 the fishery was open to unrestricted fishing for only 3 or 4 months per year. This coincided with the period of fleet expansion during those years. The fishing season was somewhat longer during the late 1970s, and there were no restrictions from the early 1980s until 1997. Again, this coincided with drastic reductions in fleet carrying capacity, followed by a period of relatively low fleet carrying capacity. Tellingly, when the size of the fleet began to increase again in recent years, there was a need for restrictions once more, beginning in 1998.

The techniques for purse-seine fishing continued to evolve during 1980-1997. In particular, the development of fish-aggregating devices (FADs) provided much greater access by purse-seiners to skipjack and bigeye tuna, and thus part of the fleet's capacity was directed at those species. As well, the technologies available for fishing for yellowfin with dolphins improved, and the productivity of yellowfin appeared to increase after 1983 (Hoyle and Maunder, 2006). While conservation problems began to appear at roughly the same fleet carrying capacity, the catches were greater during the 1990s than they were during the years leading up to 1980.

Although there are variations in the closures by species and set types, restrictions averaging about 58 days (up to 2005) have been recommended for each year since 1999, the year in which the fleet carrying capacity grew considerably beyond the target carrying capacity of 158 000 m^3, to 180 000 m^3. Under this simple reasoning, the purse-seine fleet is therefore at least 16 percent (58/365) above the carrying capacity that would produce the effort necessary for the season to last the whole year. For example, the fleet carrying capacity was 213 000 m^3 by the end of 2005; reducing this by 16 percent would result in a total carrying capacity of 179 000 m^3, which is greater than the target level of 158 000 m^3.

As the closures are the result of the interaction of stock status and fleet performance, the results of this simple analysis are consistent with the original conclusion that a purse-seine fleet carrying capacity of a maximum of about 158 000 m^3 is capable of producing the amount of effort that would keep the fishery and the stocks in good condition. If the purse-seine fleet carrying capacity were at levels of the early 1980s and early 1990s, there would probably be no need to shorten the fishing season to conserve yellowfin tuna.

This simple approach could be refined if the number of sets that the purse-seine fleet makes is considered as a proxy for purse-seine capacity. During 1999-2003 about 40 percent of purse-seine effort, or 10 800 sets per year, was directed at tunas associated with dolphins. This mode of fishing is conducted exclusively by large vessels, defined as vessels with carrying capacities of more than 363 tonnes, and the catches (221 800 tonnes on average) consist predominantly of medium to large yellowfin. Reducing this by 16 percent would bring the annual number of sets on tunas associated with dolphins to about 9 000, a level commensurate with the 158 000 m^3 total carrying capacity target.

During the same period, almost 40 percent of the effort (10 300 sets per year) took fish in unassociated schools. This type of set is conducted by a mixture of small (55 percent) and large vessels (44 percent), and the annual average catch of 150,500 tonnes is also a mixture of small yellowfin (60 percent) and skipjack (39 percent). Very few bigeye are taken by this mode of fishing. Reducing this by 16 percent would bring the annual number of sets on unassociated schools to about 8,700, also a level commensurate with the 158 000 m^3 total carrying capacity target.

During the same period, purse-seiners that fish for tunas associated with floating objects accounted for about 21 percent of the effort, or about 5 800 sets per year (13 percent on flotsam, 85 percent on FADs and 2 percent unknown). Almost 90 percent of this mode of fishing is carried out by large vessels, and the catch of marketable tunas (232 500 tonnes, on average) is a mixture of the three main species (18 percent small yellowfin, 63 percent skipjack and 18 percent small bigeye). Reduction in fishing effort on floating objects, especially for large vessels fishing on FADs, is needed to conserve bigeye. The most recent assessment for bigeye (Maunder and Hoyle, 2006) indicated that a 16 percent capacity reduction would not be not enough. Unless some way were found to avoid bigeye, a reduction of up to about 50 percent would be necessary for this sector of the purse-seine fleet, reducing the number of sets per year to around 2,900.

The resulting total of about 20 600 sets represents a reduction of about 23 percent from the annual average of 26 900 sets of all types during 1999-2003. Applying this reduction to the average fleet capacity at the end of 2005 yields a target fleet carrying capacity of about 164 000 m^3, a level more in line with the results of recent assessments.

3.2. Stock assessments and simulations

The issue of an optimal capacity for the EPO purse-seine fleet can also be studied by simulating various levels of fishing mortality for the three set types, and then examining fishery indicators, such as yield per recruit, spawning biomass and catches of the three main species of tuna (yellowfin, skipjack and bigeye) in the different set types. These simulations have been part of the regular assessment work of the IATTC staff for the last few years.

The approach was first specifically used to examine the issue of target carrying capacity for the purse-seine fleet in an analysis of the maximum number of sets on floating objects that the fishery could support, prepared for the 68th meeting of the IATTC (19-20 June 2001), and in a study of alternatives to the proposed carrying capacity target of 158 000 m^3 reported in the background paper for the fourth meeting of the Permanent Working Group on Fleet Capacity, held in Panama on 31 July-2 August 2000. Similar studies have been carried out regularly since 2000.

In these studies, typically, the sustainable yields are estimated for each of the three species, for both the surface and longline fisheries, because management decisions taken for the purse-seine fleet affect other components of the fishery. The estimates for yellowfin, skipjack and bigeye have been made using the A-SCALA stock assessment model of Maunder and Watters (2003). (A simpler procedure that assumes that the catch is proportional to fishing effort was used earlier for skipjack.) The results of these studies have been very consistent.

For example, in one of the more detailed studies (Maunder and Watters, 2002), the 1999 levels of fishing effort were used as the base case, and the effort that would maximize the yellowfin catch was estimated, using combinations of various levels of effort for the three modes of fishing. In another set of simulations in the same study, effort levels of 40 percent greater than the 1999 level and 40 percent less than the 1999 level were used for the three types of purse-seine sets.

Results of this study showed that if the capacity of the part of the fleet fishing only for tunas associated with dolphins were increased by 90 percent the fishery would still be sustainable. However, this would reduce the spawning biomass to only 16 percent of its unexploited level, increase the catch of yellowfin tuna by only 5 percent (11 000 tonnes) and reduce the average catch per vessel fishing for tunas associated with dolphins by about 50 percent. Thus, while the fishery would still be sustainable if the capacity of the fleet fishing for tunas associated with dolphins were allowed to increase, the catch per vessel would be significantly reduced, and the catch would be only slightly increased. If, in addition, the effort on floating objects and unassociated schools were reduced to 75 percent of the 1999 level, the catch of skipjack would decrease by 66 000 tonnes, while that of bigeye (by purse seiners and longliners combined) would increase by only 2 000 tonnes.

In general, because the curve that relates yield to fishing effort for yellowfin tuna is flat near the average maximum sustainable yield (AMSY), increases or decreases in fleet capacity would have relatively little effect on the AMSY of yellowfin. Thus, these results (and the consistent simulations carried out each year as part of the regular assessment work of the IATTC staff) show that there are advantages for the fishery in maintaining a fleet size that maximizes the combined catch of yellowfin, skipjack and bigeye, while keeping catch per vessel and longline catches at healthy levels. A total capacity of 158 000 m^3 for the purse-seine fleet would achieve this result.

4. TARGET LONGLINE FLEET SIZE

What is usually considered to be the longline tuna fleet in the EPO consists mostly of "industrial" vessels with overall lengths greater than 24 m, with freezing capability. These are referred to in recent IATTC documents as LSTLFVs (large-scale tuna longline fishing vessels).

The problem of establishing a target carrying capacity for this fleet is, in some respects, similar to that for the purse-seine fleet. However, the data for the purse-seine fleet are much more extensive and detailed; for example, only recently have catch and effort data been available for all the major longline fleets fishing in the EPO, and those data only for the last few years. Annual data for some large-scale fleets and for the numerous artisanal vessels in the EPO are unavailable, and the IATTC's Regional Vessel Register is more nearly complete for purse-seine vessels than for longline vessels. However, even if it were complete, the Register, in many cases, simply lists all longline vessels authorized to fish in the EPO, and would not be useful for determining which vessels were actually fishing in the EPO during any given period.

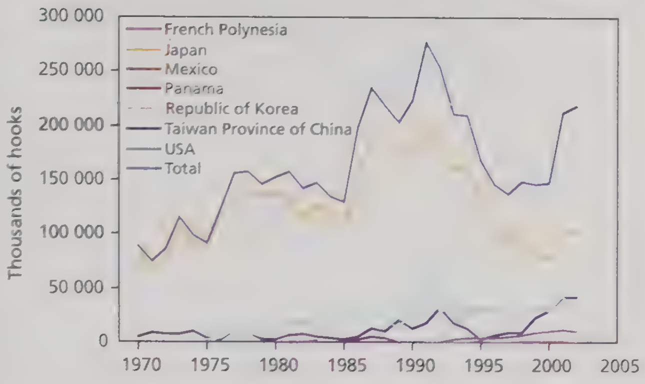
One important difference between the purse-seine and longline fisheries is that the latter generally catch large fish, so most of their catches in the EPO consist of bigeye and, to a lesser extent, yellowfin and albacore (*Thunnus alalunga*) tuna. Only small amounts of skipjack are taken by the longline fleet. Some longline vessels direct their effort at swordfish (*Xiphias gladius*), and significant amouts of marlins and sharks are taken by the longline fishery directed at tunas.

Although the issue of longline effort has been discussed extensively in recent years, the question of the number of LSTLVs and of the "optimal" longline carrying capacity has not been approached formally. However, the declining catches and catch rates, and the status of some of the stocks, have led some governments to seek ways to reduce the capacity of the longline fleet. In this regard, Japan's initiative to reduce the number of LSTLVs in its fleet by 20 percent by scrapping 132 vessels, in accordance with the FAO *International Plan of Action for the Management of Fishing Capacity*, is noteworthy. In recent resolutions by the IATTC, states and fishing entities with LSTLVs have been encouraged to undertake similar initiatives and to not increase their fishing effort in the EPO. During 2005-2006 the Taiwan Province of China has been carrying out a fleet reduction programme, which involves scrapping 160 large-scale vessels, including vessels that were or are currently operating in the Pacific Ocean. The Republic of Korea and other states with longline vessels have taken, or are considering taking, similar steps.

4.1 Fleet size and conservation

The annual longline catches of bigeye by the Japanese fleet, which is larger than any other longline fleet in the EPO, fluctuated around 50 000 tonnes during 1970-1985. The longline catches increased during the late 1980s and the early 1990s, reaching a peak of 85 000 tonnes for Japan and 104 000 tonnes for all fleets combined in 1991. Thereafter they declined, to a low of 36 000 tonnes for all fleets combined in 1999, and have fluctuated between that and 73 000 tonnes since then. The annual combined catch of yellowfin remained relatively stable between 13 000 and 29 000 tonnes during 1985-2004.

FIGURE 2
Longline fishing effort in the eastern Pacific Ocean



The nominal effort for Japan was more than 100 million hooks from 1976 to 1996, ranging from 104 million to 200 million in 1991, and then declining to 79 million in 2000. The nominal effort for Japan, the Republic of Korea and the Taiwan Province of China combined was 133 million hooks in 2000. However, in 2001 the effort by Japanese vessels increased to 102 million hooks, and that for Japan, the Republic of Korea and the Taiwan Province of China combined increased to 230 million hooks. In 2002 the effort for those three countries combined increased to 279 million hooks (Figure 2).

Until recently, there have been no restrictions on the longline fishery in the EPO. Thus, in considering a target fleet size for the EPO, the approach of calculating target capacity based on recent closures used for the purse-seine fleet would not work. The first management measures of this kind were implemented in 2004 and 2005, with the objective of ensuring that the annual longline catches of bigeye in the EPO would not exceed the level of 2001.

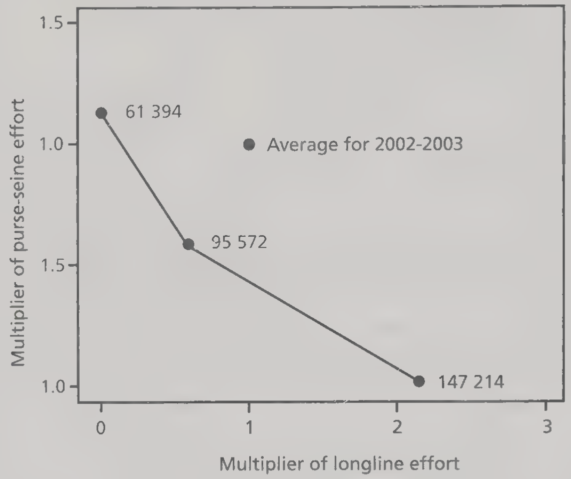
4.2 Stock assessments and simulations

In general, the assessment simulations described in Section 3, in which the effort of the different purse-seine set modes was varied, have consistently shown that the longline catch of bigeye would increase if the purse-seine effort on floating objects were reduced, and that the longline catches of yellowfin would increase appreciably if the purse-seine effort were drastically reduced. The studies have shown that reducing purse-seine effort directed at small fish would increase the spawning biomasses of yellowfin and bigeye, and the yields per recruit and catches of those two species taken by the longline fleets. However, such a reduction would also reduce significantly the large purse-seine catch of skipjack.

The most detailed study to date of the purse-seine and longline fisheries in the EPO was carried out by Maunder and Hoyle (2006). This study takes into account low levels of recruitment and increased mortality, considers effort reductions for purse seiners and longliners separately and together, and thus provides insight into the interactions of the two gears. The projections indicated that if the fishing mortality continues at the 2002 and 2003 levels, the longline catches and the spawning biomass ratio (ratio of current spawning biomass to that of the unfished population) of bigeye would decrease to extremely low levels. The purse-seine fishery on floating objects has the greatest impact on the bigeye stock, so various combinations of levels of purse-seine and longline effort could be used to produce the average AMSY. Restrictions that applied

FIGURE 3

AMSYs, in tonnes, of bigeye at various combinations of multipliers of the average longline and purse-seine fishing effort for 2002-2003



only to the longline fisheries would be insufficient to allow the stock to rebuild to levels that would support the AMSY. However, if either purse-seine or longline fishing were eliminated, the fishery would be sustainable at near maximum levels for the other fishing gear. If both longline and purse-seine fishing were reduced by the same fraction, a reduction to 57 percent of the 2002-2003 effort would produce conditions at which the AMSY could be achieved. The results, based on the assessment of Maunder and Hoyle (2006: Table 5.3), are summarized in Figure 3, which shows the optimal fishing effort for bigeye for the purse-seine and longline fisheries. For any given level of longline effort, the graph shows the corresponding purse-seine effort that would allow the AMSY to be taken, and vice versa. If only the purse-seine fishery were operating, the AMSY would be considerably less, but the current effort would be at about the level corresponding to the AMSY. This suggests that if there were no longline fishery, the current purse-seine effort would be near optimal with a smaller AMSY. If bigeye were caught only in the longline fishery, the AMSY would be almost double that estimated for the two gears combined. To achieve this AMSY level, the longline effort would have to be doubled, to more than the levels observed in the late 1980s and early 1990s. This suggests that, prior to the expansion of the purse-seine fishery on floating objects, the bigeye stock was probably near a level that would have produced an AMSY of more than 100 000 tonnes.

The level of fishing effort by the two gears corresponding to the AMSY shown in the middle of the graph is about 57 percent of the average for 2002 and 2003 level of effort, assuming that fishing mortality is proportional to fishing effort, and the patterns of age-specific selectivity in both fisheries are maintained. Reducing combined effort by 43 percent increases the long-term average yield of bigeye, and would increase the spawning biomass of the bigeye stock significantly.

As Maunder and Hoyle's (2006) study and similar assessments and simulations show, the implications for fleet capacity in the EPO depend on how reductions in effective effort are made. The main target species for longlines is bigeye, and changes in fishing mortality are roughly proportional to changes in the number of vessels or the numbers of hooks deployed. Greater sustained catches of bigye are obtainable with greater reductions in purse-seine effort. However, the purse-seine fishery on floating objects catches mostly skipjack, and it may be possible to reduce its effective effort on bigeye by changing fishing practices, as Harley, Tomlinson and Suter (2004) showed that a few vessels were responsible for a relatively large portion of the catch of small bigeye. Although it could be an effective overall conservation measure, simply reducing the fleet size is probably not the best way of reducing effective fishing effort on bigeye.

In summary, it is clear that the fishing effort for both fleets combined is more than what would be desirable for bigeye conservation. However, the choice of what changes in each of the fleets to reach an optimal position on the graph is a management decision to be made by the Commission.

5. PARTITIONING FISHING EFFORT

The multi-species, multi-gear issues in the EPO might be simplified by separating two aspects of the fishery. The first is simply the purse-seine fishery for yellowfin associated with dolphins. The second is a combination of the longline fishery targeting bigeye tuna and the purse-seine fishery on floating objests that catches mostly skipjack and bigeye tuna. Together these take about 80 percent of the yellowfin, skipjack and bigeye catches in the EPO. The fisheries are largely separate, as different nets are used by purse-seiners directing their effort towards tunas associated with dolphins and those directing their effort towards tunas associated with floating objects. For a first approximation, the optimization of fishing effort for the EPO can be addressed separately for these two fisheries. The approach does not take into account the effect on the total yield and sustainability of the stock of the yellowfin caught in sets on floating objects or sets on unassociated schools, nor in the longline fishery. These would be affected by controls on the vessels directing their effort at tunas associated with dolphins or floating objects, as the larger vessels, at least, target primarily tunas associated with either dolphins or floating objects, and make sets on unassociated schools opportunistically. An approach to this type of analysis is described briefly below.

5.1 Purse-seine vessels taking yellowfin associated with dolphins

Since 1993, each purse-seine vessel that fishes for yellowfin associated with dolphins in the EPO has been required to have a dolphin mortality limit (DML). The number of such vessels has been relatively stable. An average of about 100 purse-seine vessels held DMLs during each year from 1993 to 2006, and during 2002-2006 the number has ranged from 93 to 108.

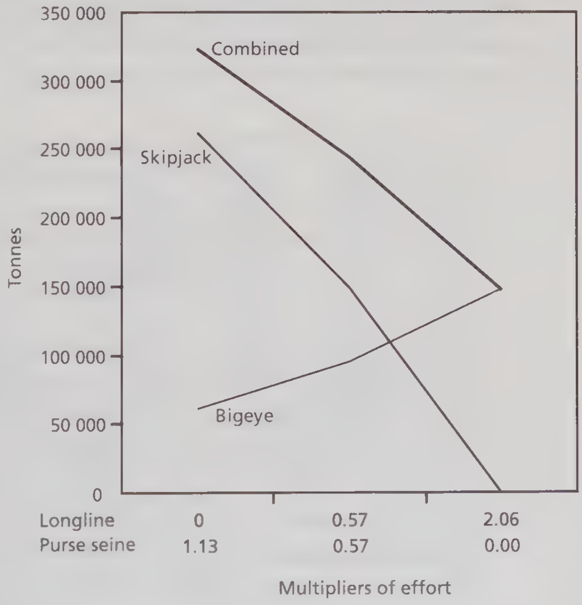
Carrying capacity limits on the purse-seine vessels with DMLs could be used as the principal control directed at bringing the carrying capacity of the fleet into line with the productivity of the yellowfin stock. Carrying capacity controls on the vessels with DMLs would, of course, also limit the catches that those vessel could make on tunas not associated with dolphins. The analyses described in Section 3.1 above suggest that a relatively modest reduction of fishing for tunas associated with dolphins is desirable.

5.2 Purse-seine vessels using FADs and longline vessels targeting bigeye tuna

The AMSYs of bigeye corresponding to different combinations of fishing mortality for longline and purse-seine fishing effort are shown in Figure 3. The AMSY of skipjack in the EPO is not known, but at levels near or below current purse-seine effort (in view of the assessment of Maunder and Harley, 2005) it seems reasonable to assume that the catch is roughly proportional to the fishing effort. Using that assumption and the estimates of the AMSY of bigeye from the purse-seine and longline fisheries, Figure 4, showing the AMSY of bigeye and the corresponding sustained yield of skipjack as a function of longline (or purse-seine) effort, can be constructed.

FIGURE 4

Catches of bigeye, skipjack and both species combined at various combinations of multipliers of the average longline and purse-seine fishing effort for 2002-2003



An approach like this could be elaborated as an aid to making decisions about the levels of longline and purse-seine fishing effort to catch skipjack and bigeye.

6. DISCUSSION

It is clear that trade-offs of many types must be carefully considered in the management of fishing capacity based on the results of stock assessments for target species, and particularly in establishing target capacities for the two major fleets of the EPO. This is especially important in the case of bigeye, because the optimal size of one fleet depends on that of the other. It is also true for yellowfin, as the longline fleet takes large individuals that are not vulnerable to the purse-seine fleet, although the longline catches of yellowfin are not as important as those of bigeye.

The most important results from assessments and simulations performed by the IATTC staff during the past few years, assuming that the effort for one mode of fishing is drastically reduced, are summarized in Figure 5. Effects of effort reductions are shown in the columns for the three modes of purse-seine fishing and for the longline fleet. The effects of these reductions on the catches and spawning biomass ratios are shown in the rows for the three main species. Large increases or decreases are shown as circles with plus or minus signs inside them, respectively.

In general, simulations have shown that a large decrease in effort on floating objects by the purse-seine fleet would bring about a relatively large increase in bigeye spawning biomass, and have also shown that reduction in purse-seine fishing effort directed at unassociated schools would increase the spawning biomass of yellowfin, but cause moderate decreases in the purse-seine catches of bigeye and skipjack. Studies have also shown that fishing on dolphin-associated schools essentially affects only yellowfin. Large decreases in longline fishing effort alone would bring about only moderate increases in the spawning biomass of bigeye, but large reductions in the longline catches of bigeye and yellowfin.

It is clear from the assessment results and simulations that the current carrying capacity of the purse-seine fleet, estimated at 213 000 m^3 in 2005, is above the level appropriate for proper management and conservation of yellowfin and bigeye tuna. Similarly, the current longline fleet size is above the level appropriate for bigeye tuna, given the current fishing practices of the purse-seine vessels using floating objects.

As we have seen for yellowfin tuna, a target capacity of 158 000 m^3 still seems appropriate from the point of view of optimizing the capacity of the purse-seine fleet to fish for this species.

For bigeye tuna the situation is more complex, both because longline and purse-seine fishing are important, and because it is possible that the effective effort on bigeye could be reduced by means other than reducing the capacity of the fleet. The choice of what reduction in fishing effort should be used as targets is purely a management one that the Commission should make. However, the 2005 assessment

FIGURE 5

Effects of reduction in three types of purse-seine fishing effort and of reduction of longline fishing effort on the purse-seine and longline catches (C_{PS} and C_{LL}) and on the spawning biomasses (SB) of yellowfin, skipjack and bigeye tuna in the eastern Pacific Ocean

		Floating object	Unasso-ciated	Dolphin	Longline
Yellowfin	C_{PS}	○	○	⊖	○
	C_{LL}	⊕	⊕⊕	⊕⊕	⊖
	SB	⊕	⊕⊕	⊕⊕	○
Bigeye	C_{PS}	⊖	⊖	○	⊕
	C_{LL}	⊕	○	○	⊖⊖
	SB	⊕⊕	○	○	⊕
Skipjack	C_{PS}	⊖⊖	⊖	○	○

○ 5 - 40 percent
○○ >40 percent

○ Little or no effect
⊖ Large decrease
⊕ Large increase

showed that, if equal reductions were to be made in both the purse-seine and longline effort, the target capacity for the longline fleet would be 57 percent of the 2002-2003 average, or a fleet that could deploy about 160 000 thousand hooks.

For skipjack, it is also clear that a different set of considerations would be needed if the purse-seine fleet were to be optimized to fish for that species. With current fishing practices, a target fleet capacity in that case would need to take into account the interactions between bigeye and skipjack in the purse-seine fishery.

However, the optimal capacity for both fleets combined will continue to be a moving target. This is clear from assessment results, but also when taking into account other factors not considered here in depth, such as the limited data available, especially for the longline fleet (annual detailed data on some large-scale fleets and on the artisanal vessels in the EPO are mostly unavailable), the composition of the fleet by individual vessels, current and future changes in efficiency and bycatch issues, among others.

Until a consistent multi-species management objective can be developed and implemented, or in the case of bigeye, species-specific selective fishing methods that are economically efficient and technically feasible can be implemented, it would be advisable to develop rules of thumb as fishing capacity management guidelines, particularly some based on reference points derived from assessment studies consistent with the precautionary approach. The management choices regarding these rules and the fishing capacity targets should be made by the Commission, of course.

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Estimates of large-scale purse-seine, baitboat and longline fishing capacity in the Atlantic Ocean: an analysis based on a stock assessment of bigeye tuna

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ABSTRACT

The Data Envelopment Analysis (DEA) approach for estimating fishing capacity cannot be applied effectively to tuna fisheries in the Atlantic Ocean because the available information is highly aggregated, and therefore inadequate for that purpose. This paper presents an alternative approach based on the traditional definition of fishing capacity, for which capacity is a hypothetical maximum yield that can be produced at a point in time, given the capital stock, regulations, current technology and resource abundance. The estimates of capacity obtained are based on inputs and outputs from a stock assessment of Atlantic bigeye tuna (*Thunnus obesus*) that incorporates information about age-specific selectivity and time trends in fishing efficiency. An algorithm is used to infer the potential magnitude of catches for a fishery in a given time period, assuming that the fishing mortality could be as high as the values estimated for neighbouring time periods. These are then used to infer, on the basis of the assessment results, the output capacity (in tonnes) for each fishery and for all fisheries combined. The results obtained suggest that the output capacity has exceeded the stock's potential long-term productivity since about 1992. These results are preliminary, however, as the robustness of the method should be tested, especially with regard to the level of aggregation used in the stock assessment (*i.e.* the number of fleets examined, the time steps used, *etc.*).

1. INTRODUCTION

An external Technical Advisory Committee to the *FAO Project on the Management of Tuna Fishing Capacity* has recommended that Data Envelopment Analysis (DEA; Kirkley and Squires 1999) be used to estimate fishing capacities for tuna fleets. Reid. *et al.* (2005) applied this approach to obtain estimates of fishing capacity, capacity utilization and excess capacity of the purse-seine fleet that targets tropical tunas (bigeye *Thunnus obesus*, yellowfin *T. albacares* and skipjack *Katsuwonus pelamis*) in the Atlantic Ocean. However, they found the available information to be largely inadequate because the data were highly aggregated. With the available data, it is not possible to associate the characteristics of individual vessels with their fishing effort and resulting catches at a detailed level, *e.g.*, for particular trips or months. Miyake (2005), who estimated the capacity of the longline fleets operating worldwide in recent years, also noted that the available information for longliners in the Atlantic Ocean was highly aggregated. The situation is the same for other major gear types, such as baitboats[2]. Thus, in the absence of disaggregated data, alternative approaches to measure capacity may be necessary for the Atlantic tuna fisheries.

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[1] The conclusions presented in this paper do not necessarily represent the views of ICCAT.

This paper presents an alternative approach based on the traditional definition of fishing capacity: "Capacity is ... the maximum yield in a given period of time that can be produced given the capital stock, regulations, current technology and state of the resource" (Kirkley and Squires, 1999). The estimates of capacity obtained are based on inputs and outputs from a stock assessment of bigeye tuna.

The quantitative approach presented here uses information from the assessment. Briefly, an algorithm that connects consecutive "peaks" (defined in Section 2.2) is applied to estimated fishing mortality on a fishery-by-fishery basis to obtain a time series of fishing capacity for each fishery. These are then used to infer, on the basis of the assessment results, the output capacity (in tonnes) for each fishery and for all fisheries combined. The assessment incorporates information about age-specific selectivity and time trends in fishing efficiency.

2. METHODS

2.1 The assessment and data used

The stock assessment used is a 2004 application of MULTIFAN-CL (Fournier, Hampton and Sibert, 1998) to data for Atlantic bigeye tuna. The basic data sets used and the assumptions made are described by Miyabe *et al.* (2005). The particular model run that was used in this paper was an update of the work of Miyabe *et al.* (2005), which was conducted during an ICCAT stock assessment of bigeye (ICCAT, 2005). The model considered the following:

- 3 regions (1: north of 25°N; 2: 25°N-15°S; 3: south of 15°S);
- 14 fisheries: 3 purse seine, 5 baitboat (pole-and-line and other surface), 6 longline;
- Quarterly catch-effort and length-frequency data for 1961 through 2002;
- Tagging information;
- Time trends in catchability of the fish for most fleets.

The MULTIFAN-CL model provided estimates of a large number of parameters related to abundance, movements, growth and fishing mortality. The assessment outputs used for the calculations below were: observed and predicted catches, fishing mortality and exploitable population size, by fishery, year and quarter.

2.2 Fishing and output capacity

An *ad hoc* approach is used in this paper to estimate maximum fishing mortality as a measure of "fishing capacity".

One of the MULTIFAN-CL model results obtained was estimates of fishing mortality for each of the 14 fisheries, by year and quarter. In all cases, the observed catches and the estimated fishing mortalities showed strong seasonal patterns.

Maximum fishing mortality for each fishery was estimated by assuming that, for a given quarter, the available (potential) fishing mortality should not change very much between consecutive annual peaks. A "peak" was defined as a value of fishing mortality that was greater than the preceding and subsequent values. The fishing mortality from a peak in a given year was assumed to remain available until the next peak several years later.

Let m be the time of a peak and n be the time of the next peak, y denote year, q denote quarter and g denote the fishery:

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[2] ICCAT uses the term "baitboat" for what are known as "pole-and-line" vessels by FAO and other organizations. In this paper, baitboat catches also contain minor catches made by some other surface gears, *e.g.* handlines and trolling gear.

$$\hat{F}_{y,q,g} = F_{m,q,g} \qquad \text{for } y = m \text{ to } n \text{ -1}$$

where F is the fishing mortality estimated by MULTIFAN-CL and $\hat{F}$ is the maximum fishing mortality in this paper.

Output capacity was estimated by applying the maximum fishing mortality estimates to the MULTIFAN-CL estimates of abundance (exploitable stock size for each fishery) in order to compute the potential catch that would have resulted.

2.3 Capacity utilization, MSY, excess capacity and overcapacity

Capacity utilization was estimated as the ratio of observed catch to output capacity; excess capacity was defined as the difference between output capacity and observed catch; overcapacity was estimated by subtracting estimates of maximum sustainable yield (MSY) from the overall (all gears combined) capacity output.

Although MSY is often thought of as a constant, it may vary in accordance with the fisheries that exploit the stock because different fisheries exploit fish of different age groups, and the relative intensities of the different fisheries may vary over time. In the case of Atlantic bigeye tuna, the average size of fish in the catch by all fisheries combined has decreased considerably over time. Because selectivity affects yield per recruit, and yield per recruit, in turn, affects equilibrium yield, the estimates of MSY could change substantially if the overall selectivity changes. In this paper, the approach described by Restrepo *et al.* (1994) was used to estimate MSY.

3. RESULTS

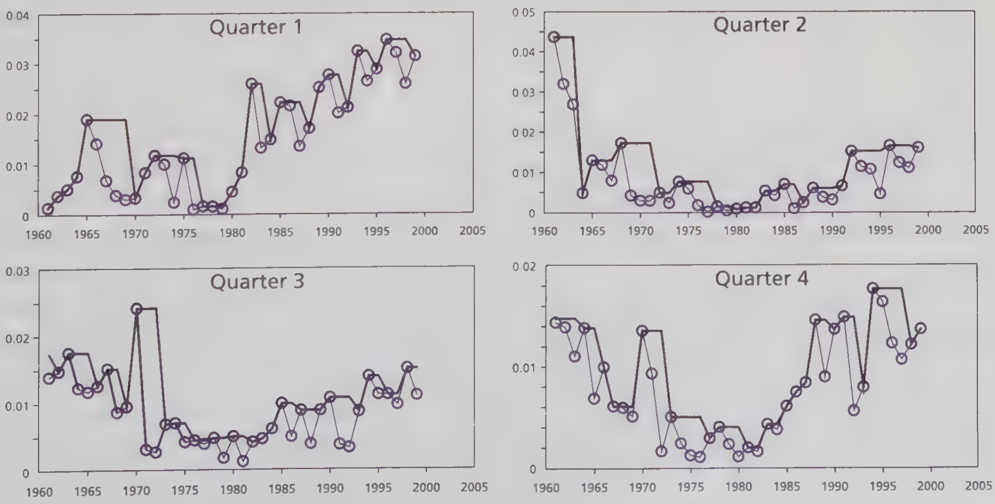
While the computations made for this study were carried out by fishery and quarter, the results were aggregated by gear type and year, which should suffice for the illustrative purposes of this paper.

3.1 Output capacity

Figure 1 illustrates how the approach used to estimate available fishing mortality was applied, using, as an example, the Japanese longline fishery in Region 2 (defined as fishery 10 in the MULTIFAN-CL analyses). Each of the panels shows the time series of relative fishing mortality for a given quarter.

FIGURE 1

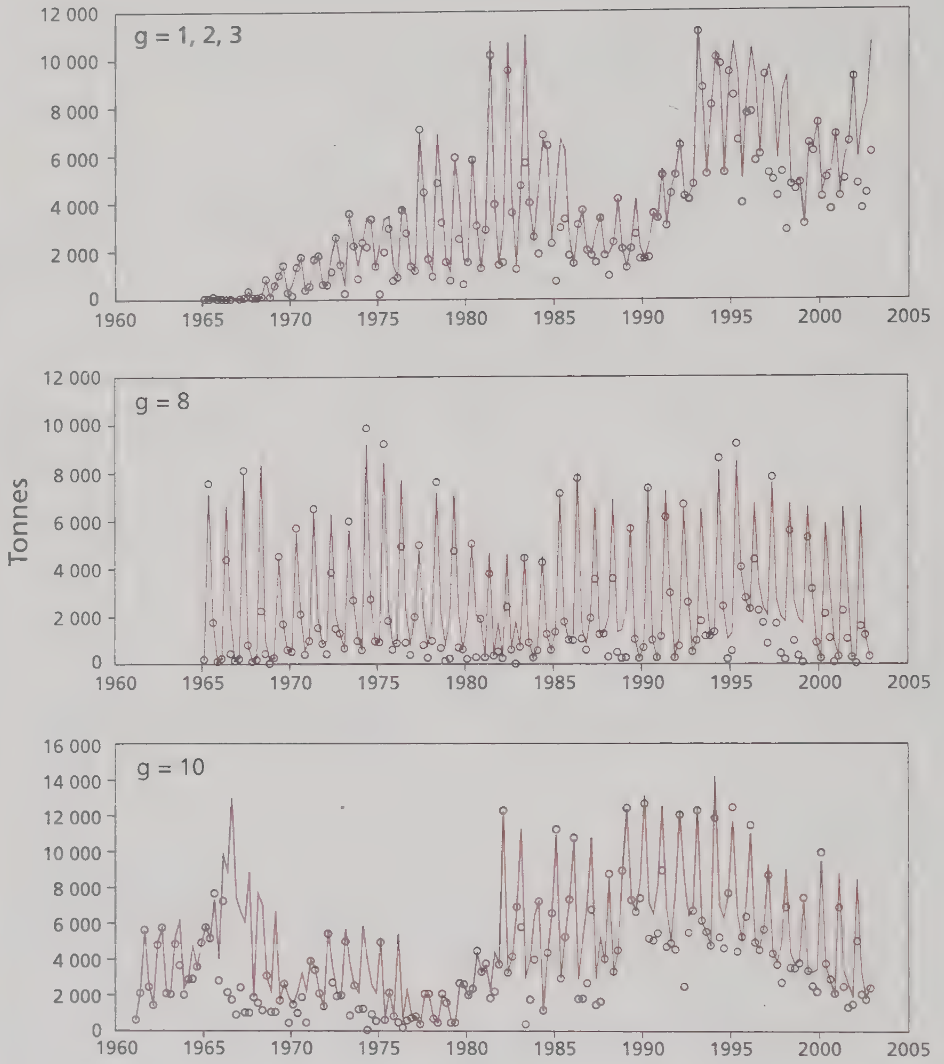
Example of how the methods to estimate fishing mortality were applied



The circles are the outputs from MULTIFAN-CL and the solid line is the maximum coefficient of fishing mortality.

FIGURE 2

Example of how the approaches applied to estimate output capacity performed for several of the 14 fisheries (g) examined



The open circles represent the observed catches, and the lines represent the estimates of capacity output. The top figure corresponds to three sequential purse-seine fisheries in Region 2; the middle figure corresponds to miscellaneous baitboat fisheries in Region 2; the bottom figure corresponds to the Japanese longline fishery in Region 2. Note that Region 2 is the area in which the majority of the catch is taken.

Figure 2 illustrates the corresponding estimates of output capacity for several of the 14 fisheries in the analyses. In all cases, the method tracked the observed seasonal pattern in fishing mortality and corresponding catches.

The estimates of capacity output are presented in Table 1, together with the observed catches.

The estimates of catch and capacity output, and the corresponding capacity utilization, aggregated by gear type and for all gears combined, are shown in Figure 3.

3.2 MSY

The relative mix of fisheries that target small bigeye and large bigeye in the Atlantic has changed considerably over time. For example, the selectivity patterns estimated by MULTIFAN-CL (all fleets combined) during the 1960s and 1990s are shown in Figure 4. The transition between predominantly longline fisheries targeting large fish

TABLE 1

Estimates of observed catch and capacity output for Atlantic bigeye tuna. The estimates are in thousands of tonnes and aggregated by gear type

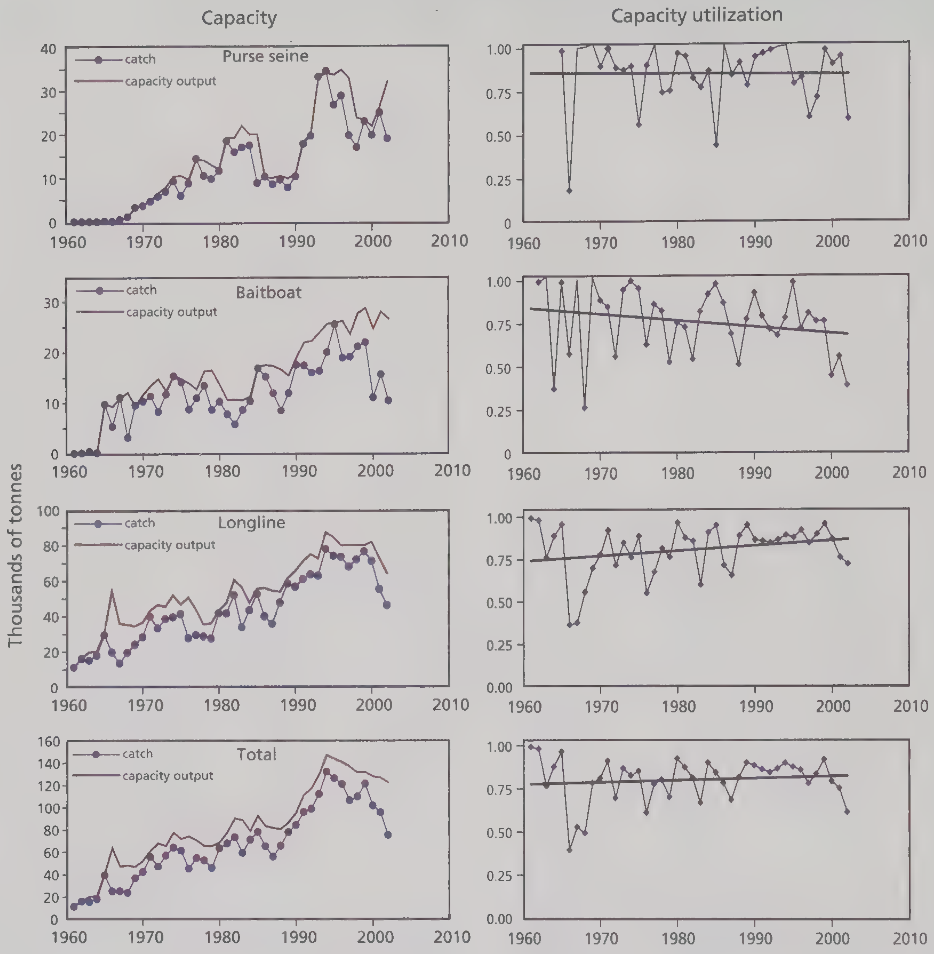
Year	Purse seine		Baitboat		Longline		Total	
	Observed catch	Capacity output	Observed catch	Capacity output	Observed catch	Capacity output	Observed catch	Capacity output
1961	0.0	0.0	0.0	0.0	11.2	11.3	11.2	11.3
1962	0.0	0.0	0.1	0.1	15.9	16.3	16.0	16.3
1963	0.0	0.0	0.4	0.4	15.0	19.8	15.4	20.1
1964	0.0	0.0	0.1	0.4	17.8	20.0	17.9	20.4
1965	0.1	0.1	9.7	9.8	29.4	30.8	39.2	40.7
1966	0.0	0.1	5.3	9.3	19.7	54.1	25.1	63.5
1967	0.5	0.5	11.1	11.0	13.5	35.9	25.0	47.4
1968	1.1	1.1	3.1	12.0	19.5	35.1	23.7	48.2
1969	3.2	3.1	9.5	9.3	24.0	34.4	36.7	46.9
1970	3.6	4.0	10.3	11.6	28.4	36.5	42.3	52.1
1971	4.6	4.6	11.3	13.4	39.8	43.2	55.8	61.2
1972	5.7	6.5	8.3	14.8	33.2	46.5	47.2	67.7
1973	6.9	7.8	11.7	12.4	38.4	45.4	57.0	65.6
1974	9.3	10.3	15.3	15.3	39.5	51.8	64.1	77.4
1975	5.9	10.5	14.1	14.8	41.3	46.7	61.3	71.9
1976	8.7	9.7	8.7	13.9	27.8	50.5	45.3	74.1
1977	14.4	14.1	10.9	12.7	29.5	43.8	54.9	70.6
1978	10.5	14.1	13.4	16.3	28.8	35.3	52.7	65.7
1979	9.8	13.0	8.6	16.4	27.6	36.1	46.0	65.4
1980	11.7	12.0	10.3	13.6	41.7	43.1	63.6	68.8
1981	18.4	19.3	7.7	10.6	41.6	47.5	67.8	77.4
1982	15.9	19.2	5.8	10.6	51.8	60.5	73.5	90.3
1983	17.0	22.0	8.6	10.5	33.8	56.3	59.4	88.8
1984	17.4	20.0	10.3	11.2	43.3	47.7	71.1	78.9
1985	8.8	20.0	16.8	17.2	52.6	55.4	78.2	92.6
1986	10.3	10.1	15.2	17.5	40.0	55.9	65.4	83.5
1987	8.5	10.0	11.9	17.3	35.6	54.3	56.0	81.6
1988	9.6	10.4	8.5	16.5	47.8	53.7	65.8	80.7
1989	7.8	9.9	11.9	15.4	58.4	61.4	78.1	86.6
1990	10.3	10.9	17.5	18.9	56.5	65.4	84.3	95.2
1991	17.7	18.3	17.4	21.9	60.8	71.0	95.9	111.1
1992	19.6	19.8	15.9	22.2	63.5	75.0	99.0	117.0
1993	33.1	32.9	16.2	23.9	62.8	72.5	112.2	129.3
1994	34.5	34.1	20.0	25.5	77.7	87.1	132.2	146.7
1995	26.7	33.6	25.5	25.8	74.1	84.4	126.3	143.8
1996	28.8	34.7	18.8	26.2	73.5	79.8	121.2	140.7
1997	19.7	32.8	19.1	23.6	67.8	80.1	106.6	136.5
1998	17.0	23.8	21.1	27.6	71.8	80.0	109.9	131.4
1999	23.0	23.3	21.9	28.7	76.5	79.9	121.4	131.9
2000	19.8	21.8	11.0	24.6	71.0	81.6	101.7	128.0
2001	24.9	26.2	15.6	27.9	55.2	72.6	95.7	126.8
2002	18.9	32.1	10.4	26.6	46.2	64.1	75.5	122.7

during the 1960s and mixed fisheries that include FAD-based purse seine fisheries targeting small fish during the 1990s is evident.

When selectivity changes as much as shown by Figure 4, the MSY will change as a function of changes in yield-per-recruit values. In this study, MSY was estimated for the entire time series in the assessment, assuming that the parameters (growth, reproduction, selectivity and stock-recruitment relationship) would remain unchanged. The estimates of MSY are presented on a quarterly and annual basis in Figure 5. The figure suggests that the MSY for Atlantic bigeye tuna has dropped considerably from about 190 000 tonnes during the early 1960s, to just over 100 000 tonnes during the 1990s.

FIGURE 3

Estimated trends in catch and capacity output and capacity utilization, by gear type and for all gears combined



3.3 Excess capacity and overcapacity

In this paper, excess capacity is measured as capacity output minus observed catch, and overcapacity is measured relative to MSY each year. The estimates of excess capacity and overcapacity are presented in Figure 6. From these, it could be concluded that output capacity exceeded the Atlantic bigeye stock's long-term productivity during the early 1990s. In absolute magnitude, the estimates of overcapacity during the last 10 years for which data are available (1993-2002) average 28 000 tonnes.

4. DISCUSSION

At present, it is not possible to use DEA to estimate the fishing capacities for all of the tuna fleets that operate in the Atlantic Ocean, primarily because the data available are highly aggregated. This paper presents an alternative approach to estimating capacity, based on the results of a stock assessment.

The approach used has some advantages and disadvantages. On the positive side, it is conceptually simple, and uses information that is readily available from the stock assessment; it is not necessary to search for other types of information that may be difficult to obtain. Also, basing the analyses on the assessment may be appealing to fisheries scientists who, like the author, are already familiar with these types of data and parameters. On the negative side, the approach used to estimate maximum effort lacks a sound theoretical basis. Also, there are some alternatives that may perform more robustly, such as applying a piece-wise regression between peaks, rather than assuming that the available fishing mortality remains constant between peaks.

A key assumption with the method proposed here is that whenever a high level of fishing mortality is estimated for a given time period, the same level is also plausible in the time periods that follow immediately after it, until the next peak occurs. Thus, peaks in fishing mortality estimated by the assessment are not considered as "outliers", but rather as levels that are achievable by a given fleet in subsequent time periods. This assumption is conceptually similar to that made by DEA and other technical-economic approaches that estimate deterministic "frontiers" of maximum production. In the context of using MULTIFAN-CL for the assessment, the analyst would be able to control the level of variability in the coefficient of fishing mortality (*F*) allowed by the model, thus guarding against the possibility of abnormally high levels of *F* driving the results. Such an option was not explored in this paper, but it is reasonable to expect that lesser variability in *F* would result in lesser estimates of capacity output.

One potential problem with the method applied is that the maximum *F* levels lag behind the observed peaks in *F* (see Figure 1). A method in which the maximum *F* would be centered at the peaks might be a more reasonable alternative. One such alternative (Appendix 1) was applied. This alternative still includes the implicit assumption that whenever a high level of fishing mortality is estimated in a given time period, that high level is also possible in the time periods immediately before and after the peak.

The analyses presented here for the fleets that target bigeye tuna suggest that the output capacity has exceeded the stock's potential long-

FIGURE 4

Average selectivity patterns (all fleets combined) estimated for bigeye tuna during two decades

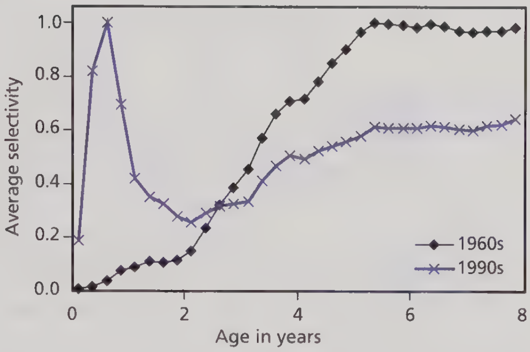
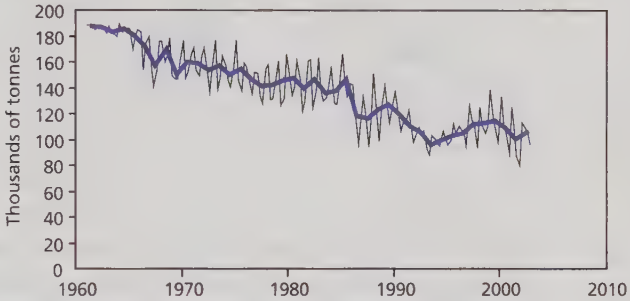


FIGURE 5

Estimated MSYs for bigeye tuna over time, assuming that the selectivity pattern during each time period remained constant over the long term



Thin line: quarterly estimates multiplied by 4; thick line: aggregated estimates by year)

FIGURE 6

Estimated excess capacity (top) and overcapacity (bottom) for Atlantic bigeye tuna fisheries (all gears combined)

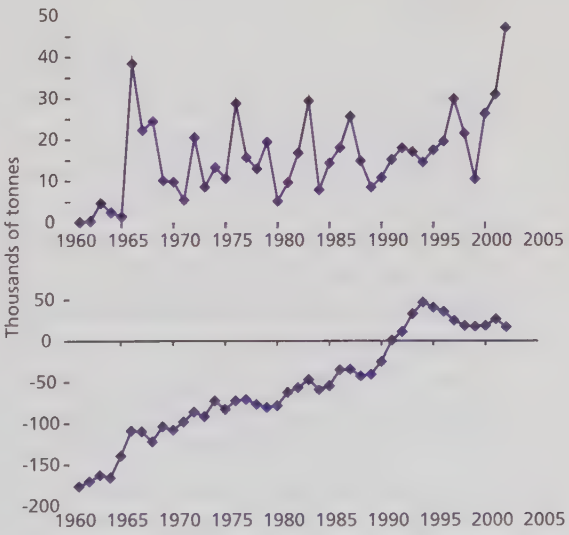
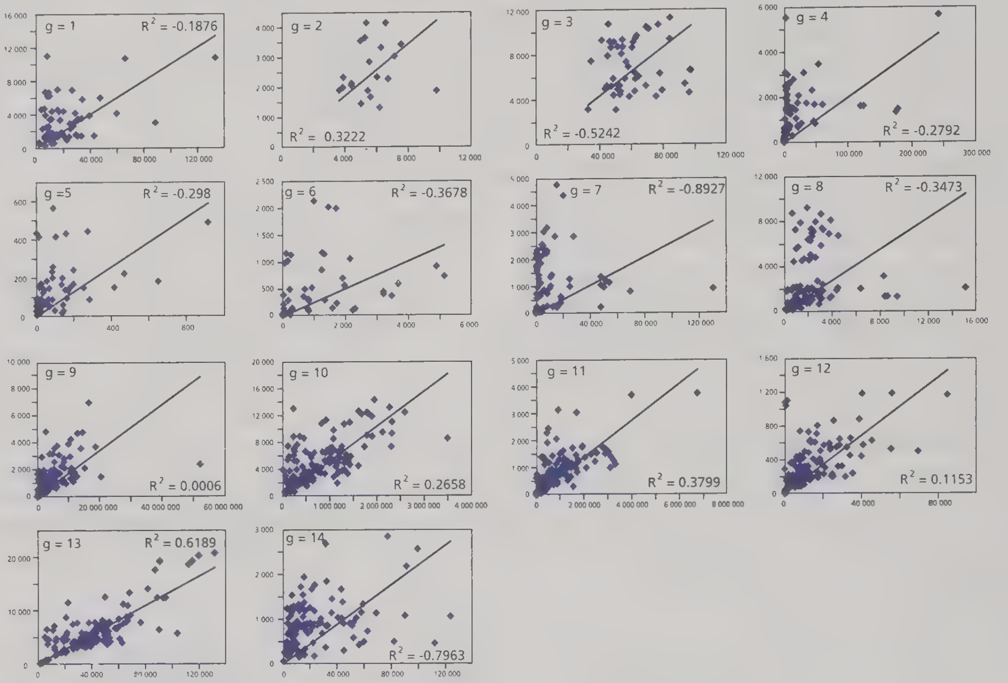


FIGURE 7
Relationship between estimated capacity output and fishing effort for the 14 fisheries (g) in the analysis



term productivity since about 1992 (Figure 6). It is interesting to note that in 1998 ICCAT adopted a binding recommendation that required all fleets catching more than 2 000 tonnes of Atlantic bigeye annually to limit their numbers of large-scale vessels that target bigeye to the average number that operated in 1991 and 1992 (*1998 Recommendation by ICCAT on the Bigeye Tuna Conservation Measures for Fishing Vessels Larger than 24 m Length Overall*). This capacity limitation was repeated in the 2004 *Recommendation by ICCAT on a Multi-Year Conservation and Management Program for Bigeye Tuna*, which implemented a comprehensive management plan that includes an overall catch limit, individual catch limits for parties, closed area-season strata and other management measures. The estimates of overcapacity in this paper appear to be in synchrony with ICCAT's decision to limit fishing capacity.

For the purpose of providing management advice, it would be useful to investigate the relationship between variable inputs (*e.g.*, fishing effort) and fishing capacity or between fixed inputs (*e.g.*, physical characteristics of the vessels) and fishing capacity. The data available for this study did not include fixed inputs. The information available in ICCAT's statistical database is mostly on nominal fishing effort (*e.g.* fishing days, number of hooks), and the level of aggregation varies by fishery. The relationship between the capacity output estimates from this study and the fishing effort series used as inputs to MULTIFAN-CL is rather poor for most of the 14 fisheries examined (Figure 7). One of the reasons for this is that the MULTIFAN-CL model allowed for changes in catchability over time, both seasonally and annually. Thus, the underlying relationship between fishing effort and fishing mortality would not necessarily be expected to be linear. Another reason is that the estimates of capacity output in each time period are conditioned by the size of the resource at that time. In either case, on the basis of relationships such as those shown in Figure 7, at first glance it would appear difficult to draw firm conclusions about the desired changes in effort for most fisheries.

This paper deals only with the multi-gear nature of fisheries that exploit bigeye tuna in the Atlantic Ocean. A multi-species focus would be much more difficult to implement with the approach presented here because the stock assessments of ICCAT are conducted on single species.

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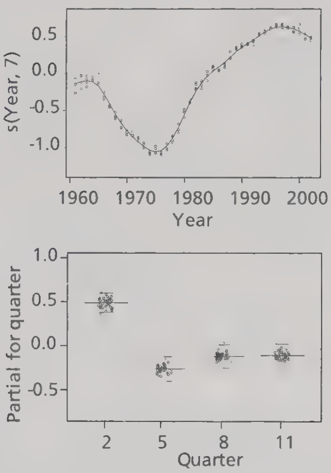
APPENDIX 1

Results obtained with an alternative method to define maximum coefficient of fishing mortality

An alternative approach was used to estimate maximum coefficient of fishing mortality (*F*) so that it would be centered around peaks. This consisted of fitting a nonparametric regression model to the estimates of *F* from MULTIFAN-CL and using the results to predict fishing mortality, by year and quarter. These predicted values were then applied to the estimated stock sizes in order to compute output capacity; in cases for which the predicted catch from MULTIFAN-CL was greater, the predicted catch was taken as the value of the output capacity.

FIGURE A.1
Partial GAM fit plots for Fishery 10 (Japanese longline, Region 2)

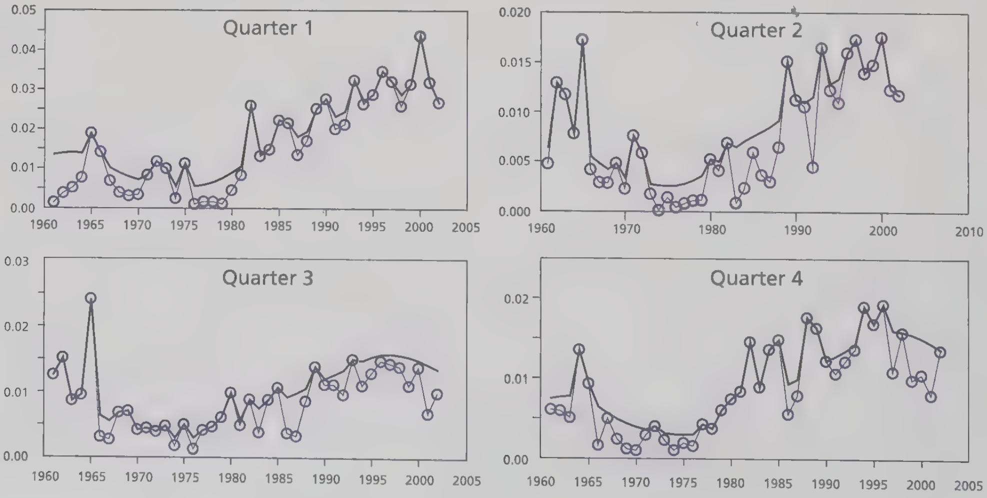


Left: smoothed nonparametric fit to the year effect; right: factor effect for quarter.

The regressions used were fishery-specific generalized additive models (GAMs) for which *F* was modeled as a spline function of year and as a factor for quarter. The degrees of freedom specified for the splines were equal to the number of years in each series, divided by 5.

The results obtained are illustrated by Figures A1-A4. Overall, these results are similar to those obtained with the "peak" method applied in the main section of this paper. However, application of this alternative method suggests that overcapacity has been decreasing more rapidly during the more recent years than does

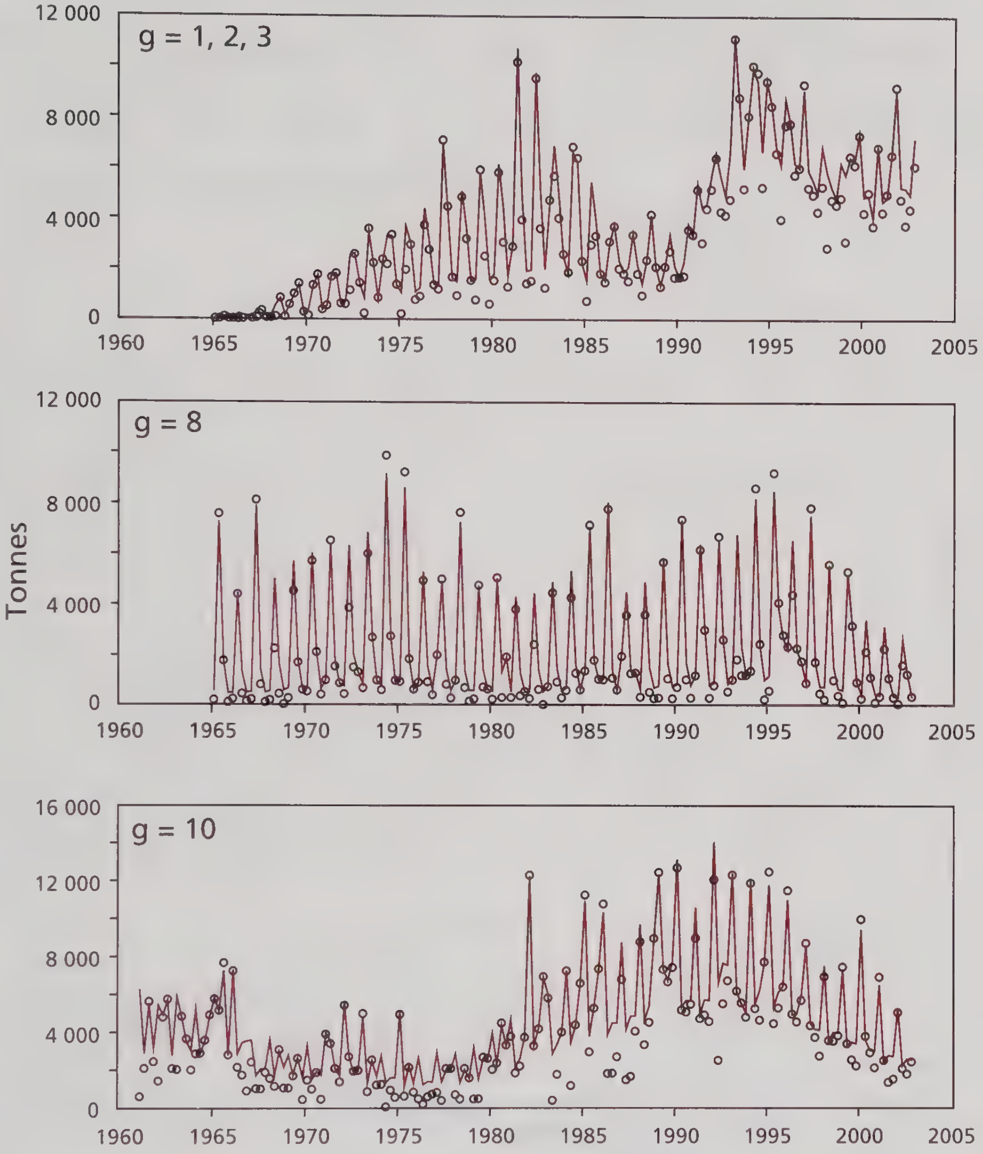
FIGURE A.2
Example of how the methods to estimate maximum fishing mortality were applied



The circles are the outputs from MULTIFAN-CL, and the solid line is the maximum of (1) fitted F from the GAM analysis, and (2) MULTIFAN-CL estimate. Data for the Japanese longline fishery in Region 2, by quarter, were used. The y axis is relative fishing mortality..

FIGURE A.3

Example of how the approach applied to estimate output capacity performed for several of the 14 fisheries examined

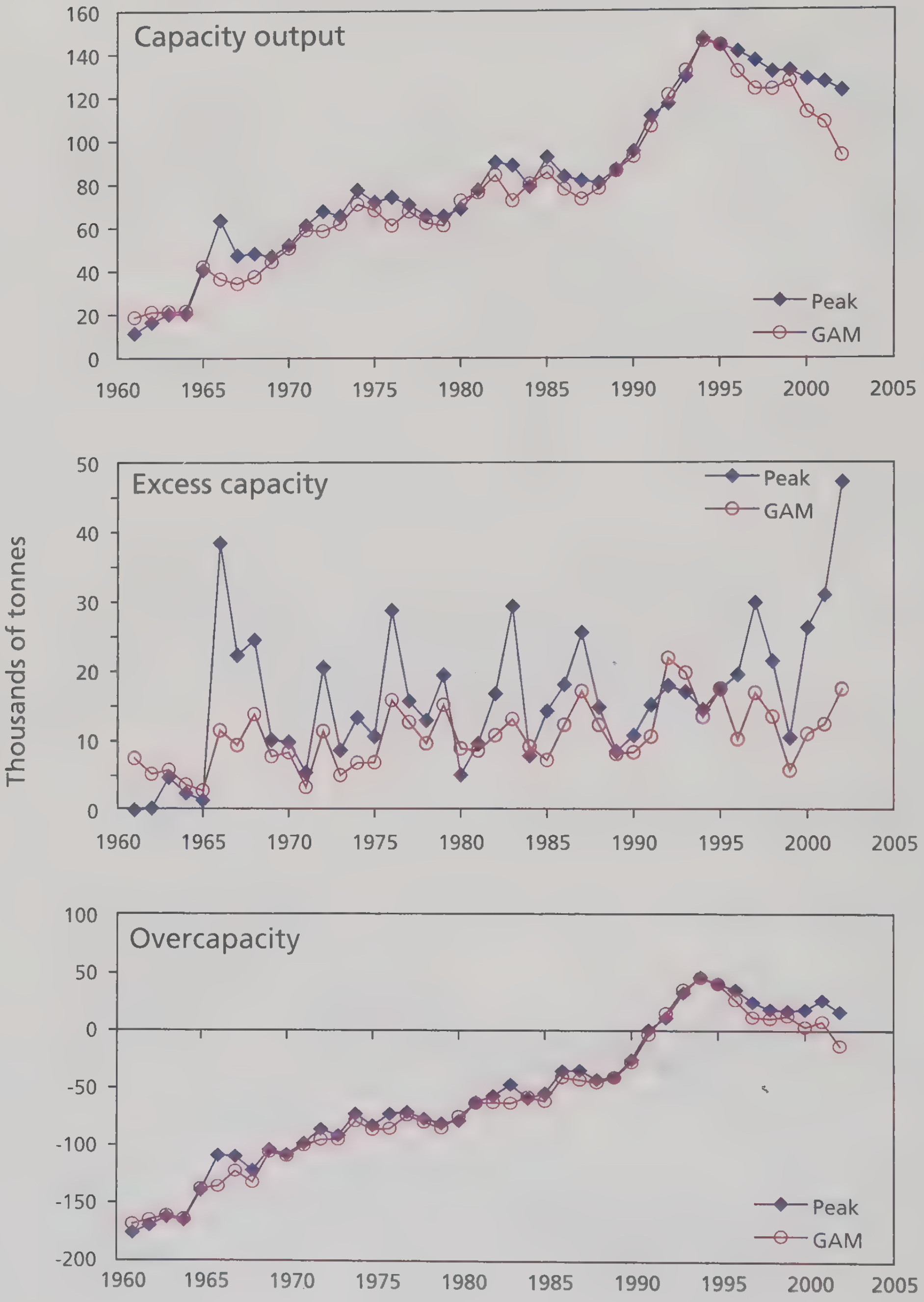


The open circles represent the observed catches, and the lines represent the estimates of capacity output. The top figure corresponds to three sequential purse-seine fisheries in Region 2; the middle figure corresponds to miscellaneous baitboat fisheries in Region 2; the bottom figure corresponds to Japanese longliners in Region 2. Note that Region 2 is the area in which the majority of the catches are taken.

the original method (see Figure A4). On the other hand, the most recent time period in the assessment is usually the most uncertain, so these results should be viewed with caution.

FIGURE A.4

Comparison of the results obtained with the "peak" method used in this paper and GAM approach applied in the Appendix



Case study of the impact of recent management measures on overall fishing capacity and fishing effort of the United States North Atlantic Ocean longline fleet

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ABSTRACT

A brief case study of recent management actions taken regarding the United States Atlantic pelagic longline fleet and their combined effect on several indicators of fleet effort and capacity for harvesting swordfish is presented. This fishery began during the 1960s, targeting primarily swordfish, and has since diversified to its present form, targeting different species, depending on the abundance of desirable species regularly taken by the gear in the area-time strata in which the vessels are able to fish. North Atlantic-wide, the amount of catch taken and the longline fishing effort expended evolved quickly, especially after mercury level restrictions for swordfish marketed in the United States were loosened in the late 1970s. Resource status evaluations of North Atlantic swordfish indicated a pattern of rapid increase in fishing mortality, leading to a period of overexploitation, followed by a period of rebuilding after management actions were adopted by the International Commission for the Conservation of Atlantic Tunas (ICCAT). There has been a measurable decline in various measures of United States Atlantic pelagic longline fishing effort and fishing capacity, which correlates with the suite of management measures taken by the United States to limit its harvest of swordfish to levels agreed by ICCAT. Over the past few years, the catches of United States vessels have been less than their total allowable catches (TACs), even though their catch rates have increased as the swordfish population has rebuilt. Fishery participants attribute the recent low harvest levels to reduced access and lower participation levels in the fishery. From the information available, there appears to be potential to improve average per hook efficiency and, by doing so, improve fleet-wide capacity to a level more appropriate for achieving the United States TACs.

1. INTRODUCTION

Upon declaration of an Exclusive Economic Zone (EEZ) in 1976, the United States established a policy promoting growth in domestic fishing capacity. By the early 1990s, this policy had resulted in the phase-out of foreign operations within its EEZ and significant increases in domestic fishing effort and catches. The programs designed to promote development of the United States fishing industry resulted in growth in domestic fishing capacities that exceeded the levels needed to extract optimal harvests from several of the nation's marine fisheries resources, and also in needs for management actions to limit harvests and fishing capacities (Hogarth, 2001)[1].

This paper provides a brief case study of recent management actions taken regarding the United States Atlantic pelagic longline fleet and their combined effect on several indicators of fleet effort and capacity for harvesting swordfish, *Xiphias gladius*. A detailed description of the management history for this fishery may be found in Amendment 1 to the US Fishery Management Plan for Atlantic Tunas, Swordfish and Sharks, available at http://www.nmfs.noaa.gov/sfa/hms/Amendment1/Final_EIS_Chapters/Chapter01.pdf. The United States Atlantic pelagic longline fishery started during the 1960s, targeting primarily swordfish, but has since diversified to its present form, targeting different species, depending on times and areas of greatest abundance of the desirable species regularly taken by the gear (Hoey and Moore 1999). After its start, the range of the longline fishery quickly expanded, and became the dominant United States gear for harvesting North Atlantic swordfish by the mid-1960s (Figure 1).

Restrictions on mercury content in the tissues of swordfish sold in the United States were established in 1971, leading to decreased landings of swordfish worldwide. In 1978, however, the maximum permissible level was raised, which revitalized the United States fishery. At the same time, the longline fleet became more efficient through changes in gear, fishing strategies and selection of areas and times for concentrating fishing effort.

Longline fishing effort and catches by longline gear expanded all over the North Atlantic Ocean (Figure 2), following a pattern similar to that for the United States fleet. Assessments of North Atlantic swordfish, carried out by the Standing

FIGURE 1

Catches of swordfish by United States vessels in the North Atlantic Ocean (open squares), proportions of the catches made by longline gear (closed circles) and five-year running averages of the latter (solid line)

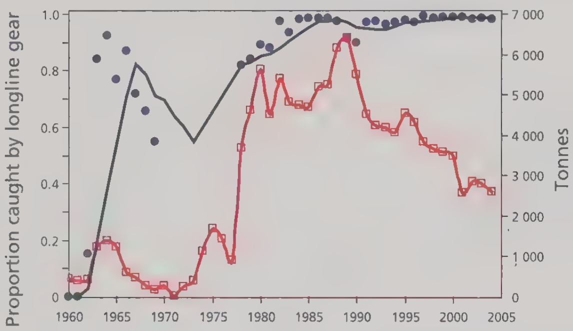
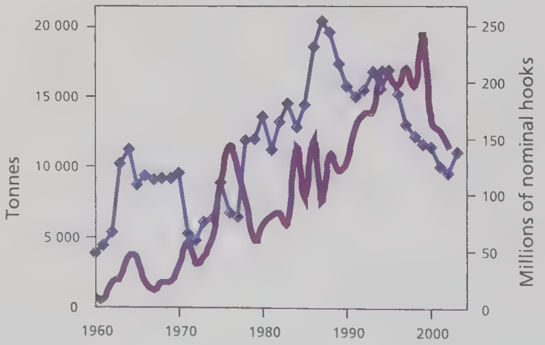


FIGURE 2

Catches of swordfish by longline vessels of all nations in the North Atlantic Ocean (diamonds) and reported numbers of hooks fished (solid line)



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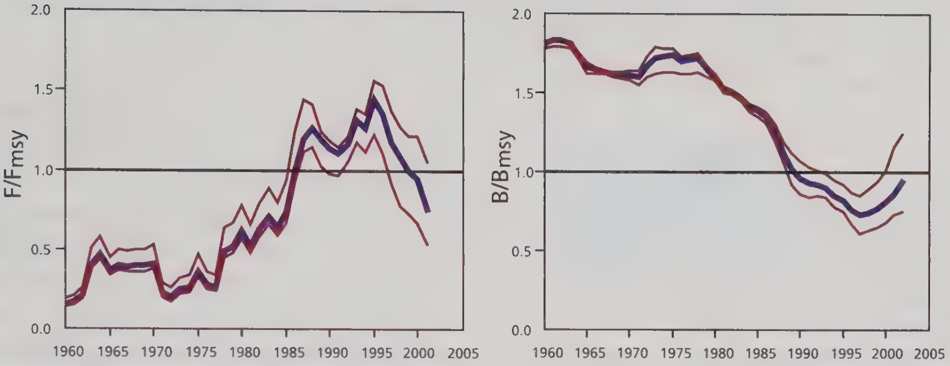
[1] Programs that fostered this growth in harvesting capacity included those that encouraged engagement in fisheries previously dominated by foreign vessels, including species that were "underutilized" in United States markets; tax credits, tax deferrals, loans and loan guarantees, which stimulated spending on new vessel construction through the mid-1980s, and also stimulated purchase, repair and refitting of fishing vessels; direct grant programs, which provided support for new product development and other projects and allocations; and trade policies designed to promote foreign market opportunities for United States producers.

FIGURE 3

Estimates of fishing mortality rate (left panel) and exploitable biomass (right panel) of North Atlantic swordfish relative to MSY benchmarks from the 2002 SCRS swordfish stock assessment



The heavy lines represent median trajectories and the thin lines the 90-percent bootstrap confidence limits.
Source: SCRS, 2003.

Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated a rapid increase in fishing mortality, leading to a period of overexploitation, followed by a period of rebuilding after management actions were adopted by ICCAT (Figure 3). The pattern of effort directed at swordfish is somewhat different from the nominal pattern, as not all of the effort is directed at swordfish, but the two patterns are similar.

2. MANAGEMENT MEASURES

During the mid-1980s the United States implemented a permit system, which led to limiting access to the pelagic longline fishery catching swordfish as a step toward managing capacity and fishing effort within the fleet.

ICCAT first agreed to conservation measures for Atlantic swordfish in 1990, after receiving scientific advice from the SCRS regarding measures to reduce fishing mortality. Among the measures agreed upon was an Atlantic-wide minimum size of 25 kg live weight (corresponding to a length of 125 cm from the tip of the lower jaw to the fork of the tail), with a limit of 15 percent of the number of fish landed for each trip of each boat that could be undersized. In 1991, the United States instituted minimum size restrictions in conformity with ICCAT agreements.

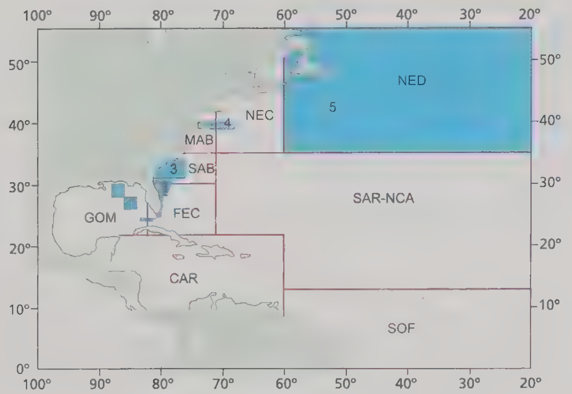
At ICCAT's 1994 meeting, following additional stock assessments, the SCRS advised that additional management measures would be needed to stop the decline in North Atlantic swordfish and to rebuild the stock to a level that could produce the maximum sustainable yield (MSY). As a result, ICCAT first established total allowable catch (TAC) levels for the nations fishing for North Atlantic swordfish in 1997. These were reduced during some of the subsequent years. In 2003, however, after the SCRS advised that there had been a measurable improvement in stock status, ICCAT increased the overall TAC to about the MSY level.

In 1999, several additional controls were imposed by the United States , including regulations to aid in tracking swordfish trade and a prohibition on importing swordfish less than the minimum size.

Additionally, ICCAT encouraged the Contracting Parties to take other appropriate measures within their national jurisdictions to protect small swordfish, including, but not limited to, the establishment of time and area closures. The minimum size regulations placed on the United States fishery had resulted in amounts of discarded fish greater than the 15-perecent limit adopted by ICCAT. The total United States catches during 1997, 1998, 1999 and 2000 exceeded the TACs for those years (although the amounts of fish landed were less than the TACs), so seasonal closures of the directed fishery were imposed when the directed in-season catches were expected to exceed the TACs. Beginning in 2001, in order to further protect juvenile swordfish and to avoid unwanted bycatches of billfish and other species, longline fishing by United States vessels was prohibited or restricted in the areas shown in Figure 4. Closures were fully implemented for all five areas by 2002. The three southernmost areas, (Charleston Bump, Florida East Coast and Desoto Canyon), were selected, at least in part, to reduce the catches of swordfish less than 125 cm in lengths and of other species. A bluefin tuna (*Thunnus thynnus*) area (Area 4 in Figure 4) was closed primarily to reduce the catches of bluefin less than the size permitted for sale by United States fishers. Longline vessels were allowed to fish in the Northeast Distant area (NED, Figure 4) if they participated in a turtle bycatch study and were accompanied by observers. In 2002, the NED was closed throughout the year to vessels not participating in the turtle study. This area has subsequently been re-opened to United States longline fishing vessels that carry observers and have agreed to utilize fishing methods designed to reduce interaction rates with and serious injuries to sea turtles. (Additional information on the program to reduce the effect of the longline fishery on sea turtles is given by Watson *et al.* (2005) and Scott *et al.* (this volume).)

FIGURE 4A

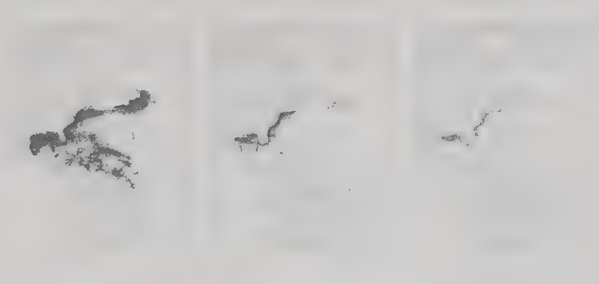
Area classification for the North Atlantic Ocean: Caribbean (CAR), Gulf of Mexico (GOM), Florida East Coast (FEC), South Atlantic Bight (SAB), Mid-Atlantic Bight (MAB), Northeast Coastal Waters (NEC), Northeast Distant Waters (NED), Sargasso-North Central Atlantic (SAR-NCA) and Southern Offshore area (SOF)



The blue areas correspond to time-area restrictions for United States longline vessels adopted for management of the harvest level of swordfish and associated incidentally-caught species: (1) Desoto Canyon, (2) Florida East Coast, (3) Charleston Bump, (4) bluefin tuna protection area, (5) Northeast Distant Waters.

FIGURE 4B

Distributions of pre- and post-closure United States longline effort (positions of first set of trip) for the periods of 1987-1996 (left), 1997-1999 (center) and 2003-2005 (right)



3. CHANGES IN FISHING CAPACITY, EFFORT AND PERFORMANCE

Since the mid-1990s, there have been declines in various measures of capacity of the United States longline fleet that fishes in the North Atlantic Ocean and the fishing effort exerted by that fleet (Table 1), which correlates with the management measures described above. The landings of swordfish by United States vessels have been less than the TACs, but considerable amounts of fish, most of which were undersized, have been discarded at sea, so the catches exceeded the TACs during 1997-2000.

The numbers of United States longline vessels targeting and catching swordfish have declined steadily since the mid-1990s (Table 1, Figure 5). The first imposition of a TAC correlates with the decline in fishing capacity and fishing effort that has carried through to the 2001/2002-2004 period, during which closed areas and seasons were also implemented. While the imposition of closed areas has had an additional effect on catch and effort (Figure 6) it is not possible to separate the effects of the minimum size limits and time-area closures to the overall reductions in catch of

TABLE 1

Measures of fishing capacity and fishing effort by United States longline vessels that fished in the Atlantic Ocean obtained from logbook data

Year	Vessels that fished	Vessels that caught swordfish	Vessels that caught swordfish in five months	Hooks reported	Year	Vessels that fished	Vessels that caught swordfish	Vessels that caught swordfish in five months	Hooks reported
1987	297	273	180	6 558 426	1996	367	275	191	10 944 660
1988	388	338	210	7 009 358	1997	352	265	167	10 213 780
1989	456	415	251	7 927 401	1998	288	233	139	8 120 273
1990	419	363	209	7 500 095	1999	226	200	143	7 996 685
1991	342	308	176	7 754 127	2000	206	185	135	8 158 390
1992	340	304	184	9 076 717	2001	185	168	114	7 897 037
1993	435	306	177	9 735 806	2002	149	140	107	7 107 958
1994	501	306	176	10 351 805	2003	123	119	94	6 862 091
1995	489	314	198	11 270 539	2004	117	114	96	7 345 048

undersized fishes nor in fishing effort, since the regulations acted in combination. There was some reduction in hooks fished during 2001/2002-2004, the period in which specific areas were closed to fishing. Some of the effort previously reported from within the now closed area along the east coast of Florida (FEC, Figure 4) was redistributed to the Gulf of Mexico (GOM) and further to the north along the United States east coast (see Figure 4 for particulars). Although the estimated amounts of swordfish less than 125 cm in length caught increased in some areas, notably the Caribbean Sea and the Gulf of Mexico, relative to the 1997-1999 average, the overall result was a reduction of approximately 50 percent in the catches of undersized fish after the implementation of the area closures, but an overall reduction in effort (in numbers of hooks) of about 10 percent relative to the average for 1998-2000, the 3-year period prior to the area closures.

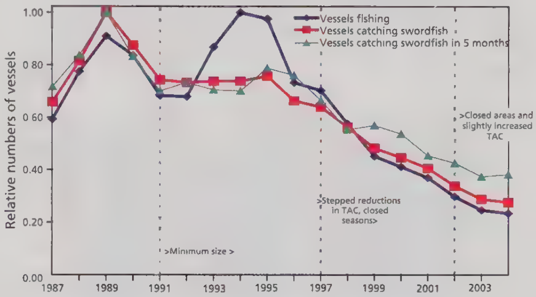
The primary factors influencing the effort and catch are undoubtedly the costs of fishing and the value of the catch. During the 1987-2004 period the inflation-adjusted prices paid for swordfish have declined, while the inflation-adjusted prices of fuel have increased (Figure 7), which has led to diversification of effort toward other species of tunas or related species.

4. COULD FLEET-WIDE EFFICIENCY BE INCREASED?

Analysis of individual vessel performance in terms of per hook productivity indicates a relatively wide range of variability within the fleet owing to a variety of factors, including the fishing methods employed by the vessel,

FIGURE 5A

Numbers of United States vessels participating in the longline fishery in the North Atlantic Ocean



The values are shown on scales relative to the maxima.

FIGURE 5A

Nominal and standardized numbers of hooks employed by United States vessels in the North Atlantic Ocean, relative to the numbers of hooks employed during 2003

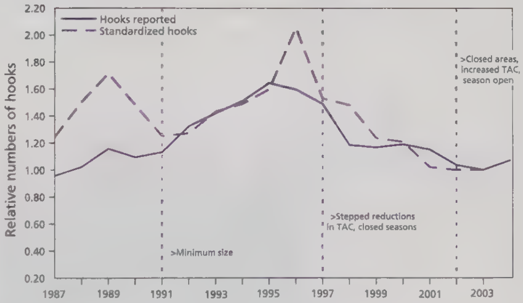
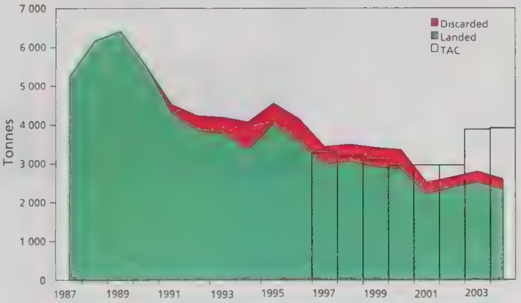


FIGURE 5C

Landed and discarded catches of swordfish by United States vessels in the North Atlantic Ocean and TACs (total allowable catches) for those longline vessels



the particular area fished, the degree of targeting for swordfish and the size of the set made. Methods applied to "standardize" the effort to remove the effects of factors independent of stock abundance, such as area, season and vessel and gear characteristics (*e.g.* Ortiz and Scott 2003) provide a basis for estimating the potential performance of the fleet if it were possible to increase the average per hook productivity to the levels of the most efficient fishing strategies. Given the most recent estimate of stock status, the current (2003) biomass is at approximately the level corresponding to the MSY. With the effort (in number of hooks) exerted in 2004, the catch per hook would have had to approximately double to achieve a catch equal to the MSY From the analysis of Ortiz and Scott (2003), it appears to be possible to increase the average catch per hook by 50 percent or more if the fleet were to fish in more efficiently (Figure 8). The degree to which this potential could be realized is unknown. Over time, estimates of relative fishing capacity and fleet capacity utilization (the proportion of the fleet employing the most efficient fishing strategy) have

FIGURE 6

Amounts of undersized swordfish caught in various areas during 2002-2004 relative to the amounts caught during 1997-1999 in those areas (upper panel) and amounts of effort expended in those areas during 2002-2004 relative to the amounts expended in those areas during 1997-1999 (lower panel). The areas are shown in Figure 4A.

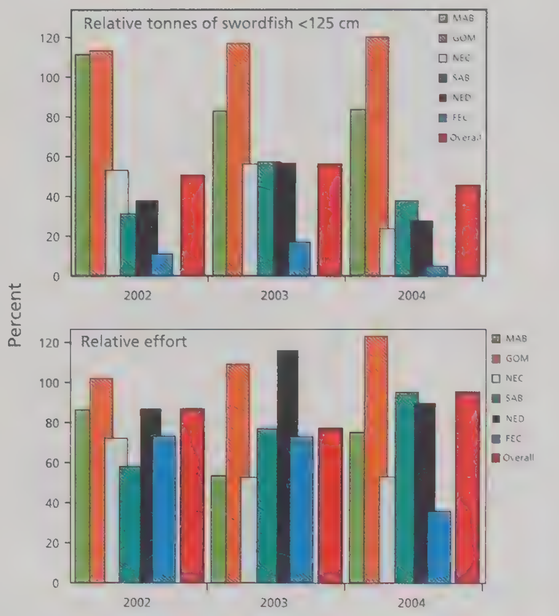
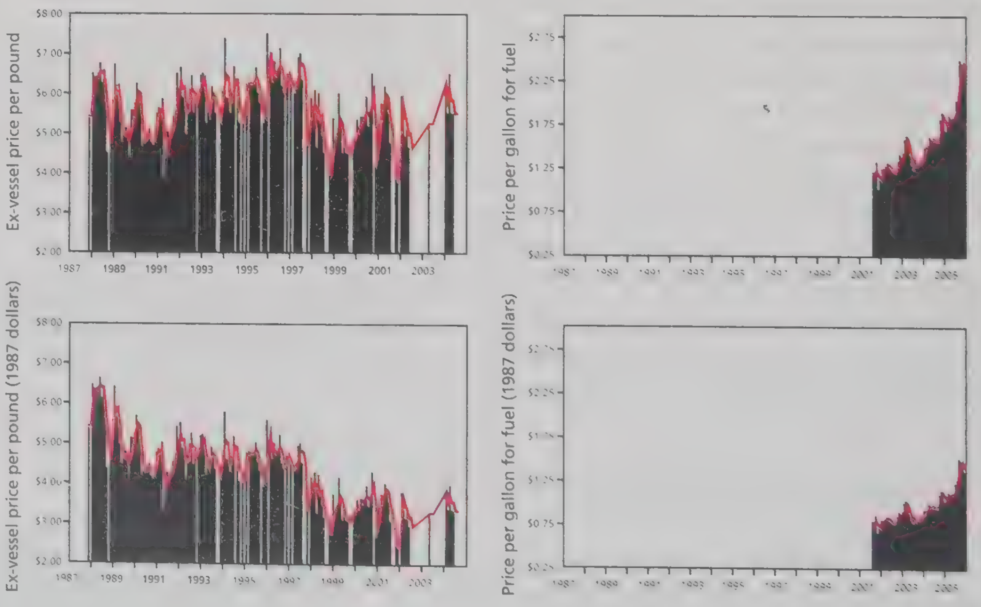


FIGURE 7

Left: Ex-vessel prices for swordfish of 100 pounds (45.4 kg) or more from Florida at the Fulton fish market in New York City.
Right: Prices per gallon (3.79 litres) paid by United States longline vessels for fuel



The amounts in the upper left panel are not adjusted for inflation, and those in the lower left are adjusted to 1987 dollars. The lines are 3-month moving averages.

decreased, but the capacity utilization ratios suggest the that it is possible to achieve greater catches per hook. (In 2004 capacity utilization is estimated to have been about 65 percent (Figure 9).)

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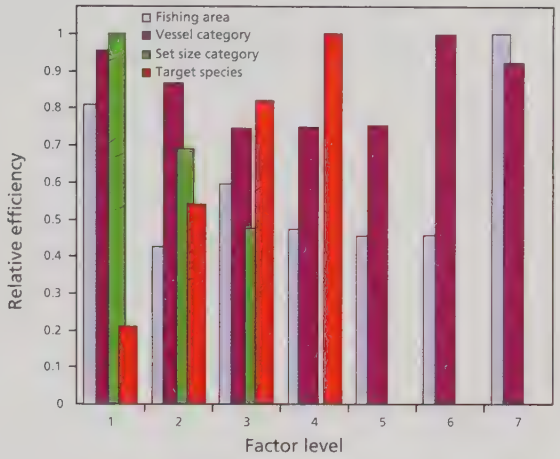
FIGURE 8

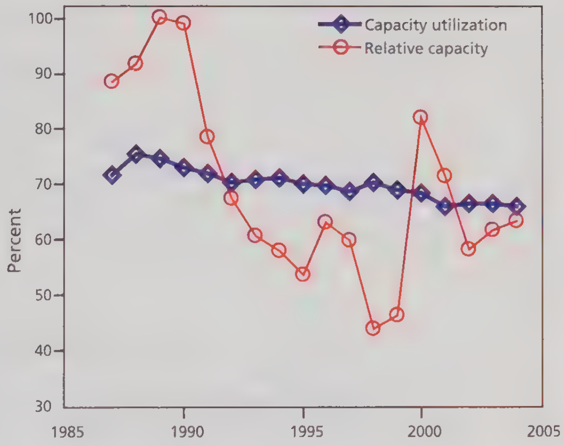
Estimates of the relative efficiencies of factors, other than abundance, important in explaining the variability in the catch rates of swordfish by United States longline vessels



A value of 1 corresponds to the greatest average level estimated for the vessel trips that were categorized (see Ortiz and Scott, 2003).

FIGURE 9

Estimates of capacity (circles) expressed relative to the time-series maximum estimated from the general linear modeling factor loadings for the most efficient fishing strategies of Ortiz and Scott (2003) and estimates of annual fleet capacity utilization (diamonds) based on logbook performance reports



Estimates of large-scale purse-seine and longline fishing capacity in the western and central Pacific Ocean based on stock assessments of target species

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ABSTRACT

Tunas are exploited chiefly by purse-seine, longline and pole-and-line gear in the western and central Pacific Ocean. While it is relatively simple to specify capacity limits consistent with the stock status of the various species, there would be a number of difficulties in applying such an approach in practice. First, the multi-species nature of the purse-seine and longline fisheries and the differential stock status of the main species make it difficult, if not impossible, for single, gear-specific capacity limits, or, indeed, other broadly-specified effort-based measures, to equally address the stock status of all species simultaneously. Second, the problem of "effort creep" is significant for capacity and other effort-based management systems. If such measures are employed, it is essential that limits are regularly reviewed and, if necessary, adjusted downwards to counter "effort creep". Third, the specification of capacity limits involves, either explicitly or implicitly, an allocation of those limits. Typically, this allocation is based on the current or recent average fishery composition. However, it is shown that altering the mix of gear types, and hence altering the overall size selectivity of the fishery, can have very different outcomes for stock status and productivity. Therefore, appropriate levels of fishing capacity in one component of the fishery will depend on the capacity in other components.

1. INTRODUCTION

The tuna fishery in the western and central Pacific Ocean (WCPO) is the largest of the world's regional tuna fisheries, with recent annual catches of the main target species (skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), bigeye (*T. obesus*) and albacore (*T. alalunga*) tuna) approaching 2 million tonnes (Appendix 1). The fishery is complex, employing multiple types of fishing gear that, in many cases, harvest the different species at different stages of their lives. The main fishing methods are longline, pole-and-line, purse seine and a variety of other types of net and hook-and-line gear. The fishery began in the 1950s, primarily as a longline fishery targeting larger albacore, bigeye and yellowfin tuna and a pole-and-line fishery targeting skipjack and albacore tuna in the western North Pacific. In the 1980s, purse seining, targeting skipjack and yellowfin tuna, began to outstrip longline and pole-and-line as the major gear type. Purse seiners also take a small, but significant, bycatch of bigeye tuna in the WCPO. Currently, purse-seine gear is responsible for approximately 60 percent of the total catch of all tunas and 75 percent of the catch of skipjack tuna in the WCPO. The catch

FIGURE 1
Distribution of purse-seine and pole-and-line catches

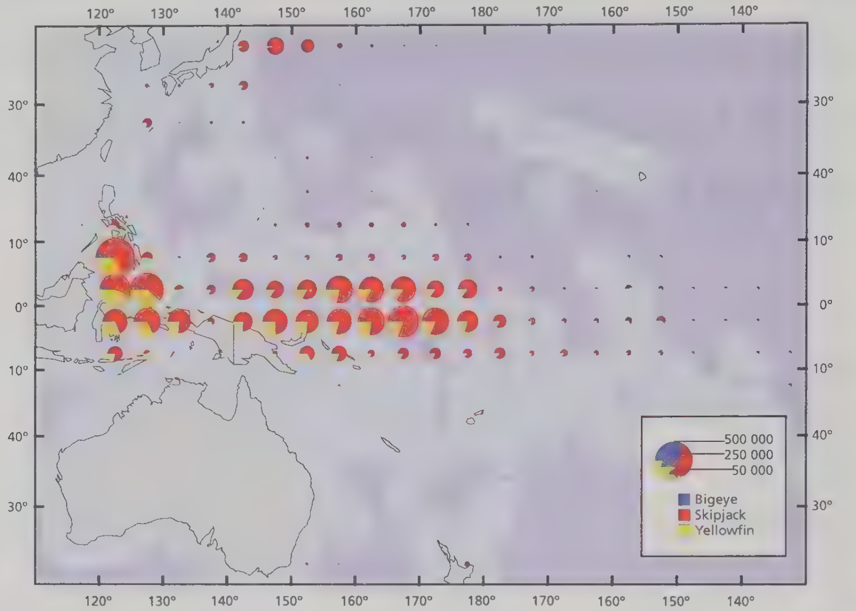
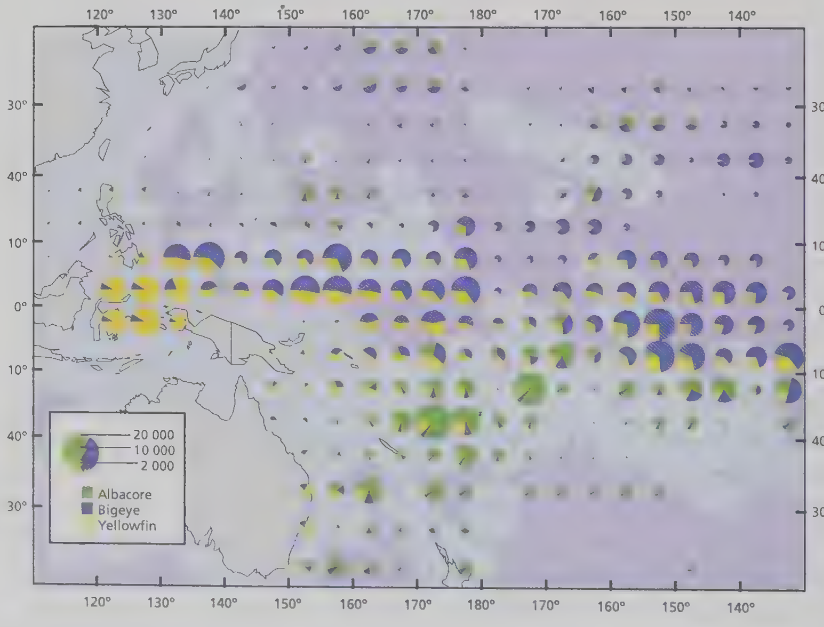

120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
30°
40°
10°
0°
10°
40°
30°
500 000
250 000
50 000
Bigeye
Skipjack
Yellowfin

FIGURE 2
Distribution of longline catches, 1999-2003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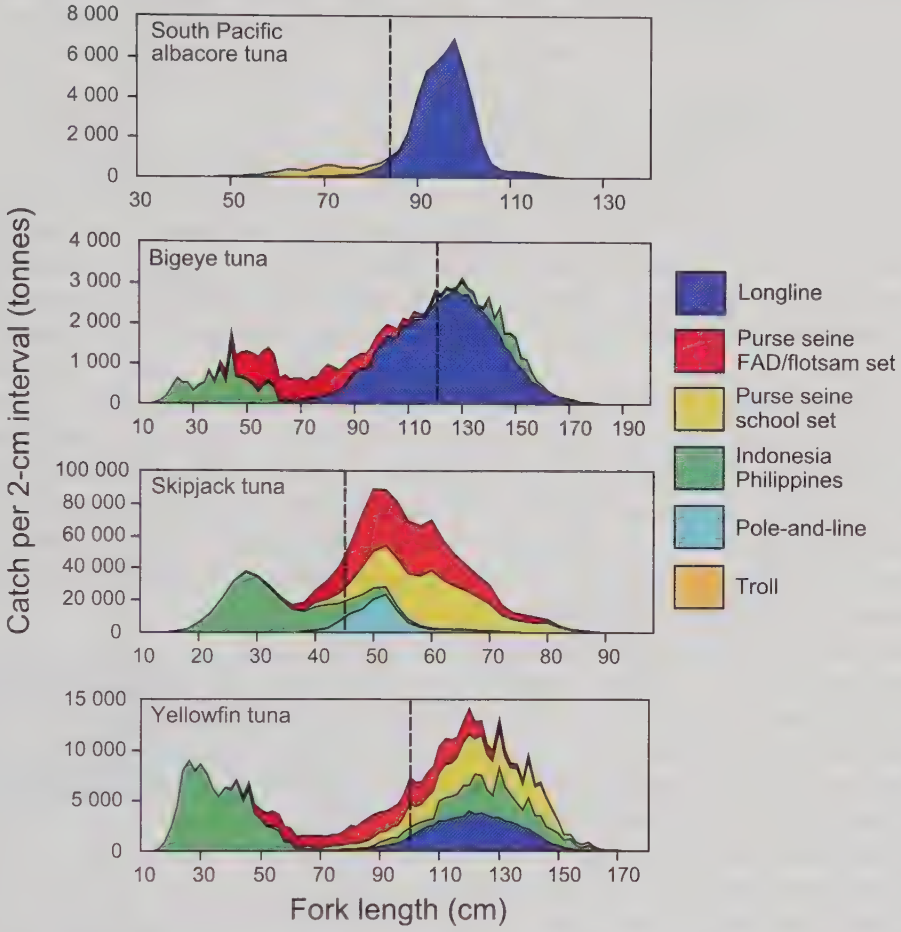
0°
10°
40°
30°
20 000
10 000
2 000
Albacore
Bigeye
Yellowfin

of tunas by purse seiners in recent years has consisted of about 68 percent skipjack tuna, 21 percent yellowfin tuna, 6 percent bigeye tuna and 6 percent albacore tuna. The purse-seine catch is concentrated in tropical waters (Figure 1). The longline catches of bigeye and yellowfin tuna occur mostly in tropical waters, and those of albacore tuna mostly in subtropical and temperate waters (Figure 2). A significant concentration of the catch by purse seines and a variety of net and hook-and-line gear types occurs in

FIGURE 3

Average size compositions of the catches of the main tuna species, by gear type, 2000-2004. The vertical dashed lines indicate the approximate sizes at 50-percent maturity



the waters of Indonesia and Philippines (Figure 1). Much of the tropical fishery occurs in the exclusive economic zones (EEZs) of Pacific Island and Southeast Asian countries and territories.

The size compositions of the catches are strongly influenced by the fishing methods used (Figure 3). The smallest skipjack, yellowfin and bigeye tuna are taken by the domestic fisheries operating in Indonesia and the Philippines. The purse-seine fishery takes mainly adult skipjack tuna greater than 40 cm in length (from the tip of the snout to the fork of the tail; FL), juvenile (<100 cm FL) yellowfin, mainly in sets on fish-aggregating devices (FADs) and on flotsam, and adult yellowfin, mainly in sets on free-swimming schools (henceforth called "school sets"). The bigeye tuna captured by purse seiners are mostly juvenile fish (<120 cm FL) taken in FAD/flotsam sets. Longlines capture adult bigeye, yellowfin and South Pacific albacore tuna, and capture greater amounts of bigeye than any other gear. The FAD-based handline fishery in the Philippines and adjacent areas captures adult yellowfin and bigeye tuna similar in size to those caught by longlines.

The establishment of the Western and Central Pacific Fisheries Commission (WCPFC) in 2004 marks the beginning of formal international management of the fisheries in that region. Management measures must be adopted to address stock status issues (see Section 2), while also promoting sustainable utilization of the stocks and the pelagic ecosystem of which they are part. Initial management measures have included a combination of fishing effort (days fished and days searched by purse seiners), catch (longline catches of bigeye) and fishing capacity (numbers of longline vessels fishing for albacore). In this paper, we attempt to estimate capacity limits (in terms of vessel numbers) that would be consistent with the 2005 stock assessments, focusing on the purse-seine and longline components of the fishery, and discuss various issues associated with the application of such measures.

2. STOCK ASSESSMENTS IN THE WCPO

Stock assessments of tunas in the WCPO are conducted, using MULTIFAN-CL, a statistical, length-based age-structured model. Most assessments incorporate spatial structure and multiple fisheries based on gear type (*e.g.* purse seine, longline), fishing method (*e.g.* purse seine FAD/flotsam and school sets) and region. Fisheries may have unique or shared characteristics of selectivity and catchability. A feature of the assessments is that catchability may be allowed to vary over time if that is considered appropriate.

Assessments are undertaken routinely for skipjack (Langley *et al.* 2005), yellowfin (Hampton *et al.* 2005a), bigeye (Hampton *et al.* 2005b) and South Pacific albacore tuna (Langley and Hampton 2005). Assessments of stock status are made using two principal biological reference points. The current (usually defined as an average over the most recent three years of the assessment, but excluding the last year) level of age-specific fishing mortality is compared with that estimated to produce the maximum sustainable yield (MSY), and the current biomass is compared to the equilibrium biomass at MSY. If $F_{current}/F_{MSY}$, overfishing is said to be occurring; if $B_{current}/B_{MSY}$ the stock is said to be in an overfished state.

Based on the 2005 assessments, overfishing was estimated to be occurring for yellowfin and bigeye tuna but not for skipjack or South Pacific albacore tuna (Table 1). None of the stocks was estimated to be in an overfished state.

TABLE 1

Biological reference points for the main tuna stocks of the WCPO, based on the 2005 base-case assessments

Stock	$F_{current}/F_{MSY}$	$B_{current}/B_{MSY}$
Skipjack	0.17	3.01
Yellowfin	1.22	1.32
Bigeye	1.23	1.25
South Pacific albacore	0.05	1.69

"Current" refers to the 2001-2003 period.

3. CAPACITY TARGETS CONSISTENT WITH STOCK ASSESSMENTS

Management measures are required to limit fishing mortality. It is theoretically possible, given suitable information on current levels of fishing capacity, to use the information from the stock assessments to derive appropriate levels of capacity for the major fleet categories fishing in the WCPO. In the following sections, we outline the various issues relating to the determination and application of capacity limits in the purse-seine, longline and other fisheries operating in the WCPO. We also look at the issue of fishery interaction and allocation, and how this may impact the estimation of capacity limits.

3.1 Purse-seine fishery

A possible methodology for relating stock assessment results to capacity limits in a simple sing-species fishery would be as follows:

- Assuming that fishing mortality is proportional to fishing effort, determine the level of fishing effort consistent with a target reference point. For example, if F_{MSY} is a target reference point, an appropriate level of effort would be

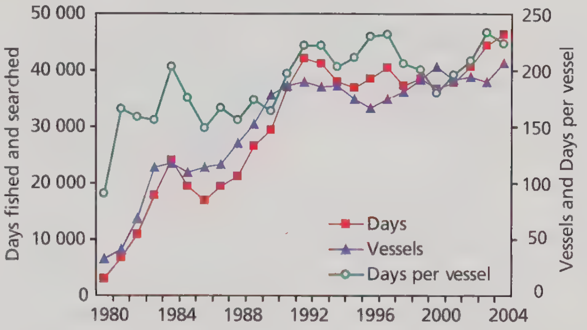
$$E_{MSY} = E_{current} \div \left(F_{current}/F_{MSY}\right) \quad (1)$$

where E = effort.

- A capacity limit consistent with E_{MSY} could then be determined, for example using an empirical relationship between fishing effort and fishing capacity. The relationship between WCPO purse-seine vessel numbers (capacity) and vessel days fishing and searching (effort) is shown in Figure 4.

FIGURE 4

Purse-seine effort (days fished and searched), numbers of vessels (Lawson 2005) and average days fished and searched per vessel



In the case of the WCPO purse-seine fishery, there are several difficulties with such a simplistic approach. First, the fishery targets principally skipjack tuna, for which, according to the stock assessment, fishing mortality (and corresponding effort, capacity and catches) could be greatly increased. For example, the current (2001-2003 average) level of fishing effort of 40 949 days (equivalent to approximately 192 vessels based on the average days fished per vessel per year during 1992-2004 of 213 days) could be expanded six-fold by applying equation (1) to the skipjack stock status estimate. However, yellowfin tuna, which is a secondary target species, and bigeye tuna, which is essentially a bycatch species, are both currently being overfished (Table 1, Column 2). In the absence of any additional measures to mitigate fishing mortality of those species, an increase in fishing effort or capacity designed to increase the catch of skipjack tuna would result in further overfishing of yellowfin and bigeye tuna. On the other hand, if the simplistic procedure described above were applied using yellowfin and bigeye tuna stock status estimates, fishing effort and capacity would have to be reduced on the order of 20 percent (to 33 291 days and 156 vessels) to be consistent with F_{MSY} reference points for those species. Such a measure would be expected to slightly increase long-term average catches of yellowfin and bigeye tuna (according to the equilibrium yield model). However, it would be expected to reduce the average catch of skipjack tuna by approximately 20 percent because the skipjack yield-effort relationship is approximately linear at current levels of exploitation (Langley *et al.* 2005). Because skipjack tuna comprises the majority of the purse-seine catch (exceeding 1 million tonnes in 2004, Appendix 1), a reduction in fishing effort and catch of this magnitude would have significant economic ramifications, and therefore such an option is not politically acceptable.

A second difficulty is that a limit on the number of purse-seine vessels would not necessarily limit fishing effort, and therefore fishing mortality. The average number of days fished per vessel per year has tended to increase over time in the WCPO purse-seine fishery (Figure 4), fluctuating between about 180 and 230 days per vessel per year since 1992. The entry of larger vessels with greater carrying capacities into the fishery, more vessels being based in coastal states close to the fishing grounds, more modern unloading facilities, more options to select unloading ports and the use of at-sea transhipment and tendering could all allow vessels to spend more time per year fishing. At current levels of annual fishing effort per vessel, there would appear to be considerable potential to increase fishing effort even if the number of vessels was limited at the current level. If capacity limits were based on carrying capacity, rather than on vessel numbers, the capability to increase fishing effort would be somewhat more constrained.

A third difficulty is that even if fishing effort were constrained by capacity limitation, fishing mortality may still be increased by increased catchability (fishing mortality per unit of effort). Increased catchability might result from the adoption of new technology

FIGURE 5

Estimated purse-seine fishing mortalities (F)1 and fishing mortalities per unit effort (catchability) for skipjack, yellowfin and bigeye tuna

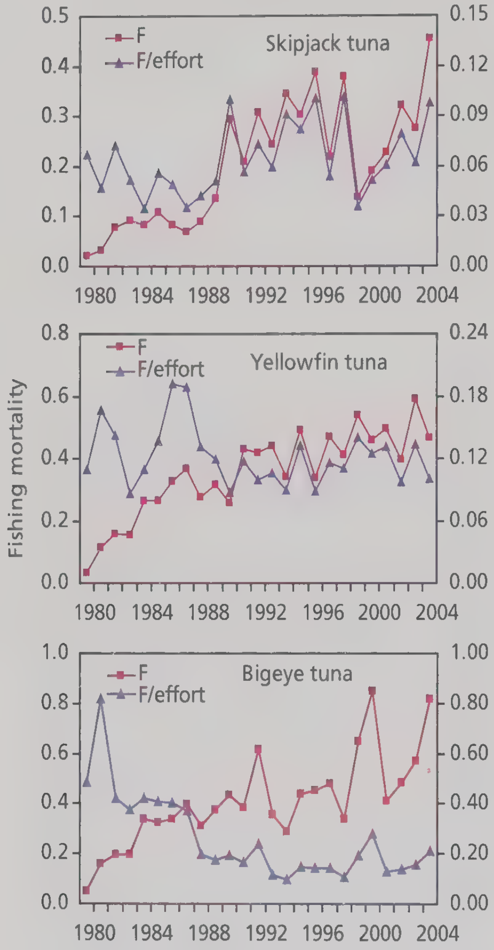
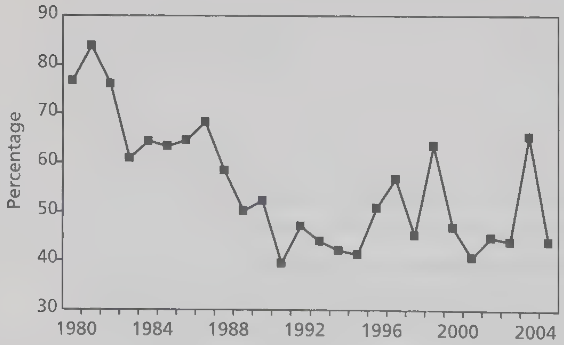


FIGURE 6

Percentages of FAD/flotsam sets in the total annual purse-seine sets in the fishery of the WCPO



that assists in the location and capture of tuna schools, such as the use of drifting or anchored FADs. Fishing mortality for the three species has increased over the past 25 years but catchability has shown less consistent variability (Figure 5).

For skipjack, catchability by purse seine is estimated to have increased in the late 1980s, decreased in the late 1990s and increased since that time. For yellowfin, catchability has been more stable over time, while for bigeye catchability is estimated to have decreased to the mid-1990s after which it tended to increase. Some of the variability in catchability is, no doubt, related to environmental variation. However, other changes are due to changes in the operational characteristics of the purse-seine fleet, in particular in relation to set type. For bigeye, set type is known to have a particularly profound effect on catchability and fishing mortality of bigeye tuna. The only significant purse-seine catches of bigeye tuna occur in FAD and flotsam sets, with only small catches occurring in school sets (Figure 3). In the early 1980s, the purse-seine fishery was highly dependent on FAD/flotsam sets (Figure 6).

With the arrival of United States vessels in the WCPO, the set-type profile of the fleet shifted more towards school sets, and by the early 1990s more than half of the total purse-seine sets were school sets. Since that time, the proportion of FAD/flotsam sets in any given year has varied from 40 percent to 65 percent of the total sets (Figure 6). The resurgence in FAD/flotsam sets in the past decade is due largely to the deployment of drifting FADs by purse-seine vessels. Drifting FADs may be located electronically, and in some cases may also transmit information on the size of tuna aggregations to assist vessel operators in FAD selection. These changes in the set-type characteristics of the fleet, and the use of high-technology FADs in particular, have been a major factor influencing catchability and fishing mortality of juvenile bigeye tuna (Figure 5). In this case, it is clear that simple capacity limits, or even limits on fishing effort, will not necessarily control fishing mortality effectively. The number of FAD/flotsam sets, rather than total purse-seine effort or capacity, will be the major factor influencing fishing mortality of bigeye tuna.

To summarize, there are three key difficulties that would need to be addressed in determining and applying purse-seine fishing capacity limits as a means of limiting fishing mortality:

- Capacity limits would not be able to recognise the differential stock status of skipjack tuna compared to yellowfin and bigeye tuna.
- Capacity limits may not limit fishing effort because of the potential of the fleet to increase the amount of fishing effort per vessel.
- Capacity limits may not limit fishing mortality because of increases in catchability over time.

The second and third issues above fall broadly into the category of "effort creep". These might be dealt with through continual (downwards) adjustment of fishing capacity if annual assessments indicate increased fishing mortality per capacity unit. However, capacity limitation, or indeed fishing effort limitation alone, will not be able to deal with the issue of the multi-species nature of the fishery and differential stock status. Species-specific catch limitation or effort controls targeting FAD/flotsam sets would appear to be the only means of effectively dealing with this issue.

3.2 LONGLINE FISHERY

The longline fishery in the WCPO may be classified into two major groups: 1) large-scale vessels (typically greater than 24 m in overall length and equipped with superfreezing facilities, which makes their catches acceptable to the lucrative sashimi market) operating throughout the WCPO and targeting bigeye, yellowfin and, to a lesser extent, albacore tuna; and 2) vessels, commonly called offshore longliners (usually less than 24 m in overall length and without superfreezing capability) operating within restricted ranges of local fishing bases and targeting bigeye, yellowfin, albacore and, in some areas, broadbill swordfish (*Xiphias gladius*). (It should be noted, however, that in recent years the numbers of longliners less than 24 m in overall length have increased, and some of these are equipped with superfreezing facilities (Miyake 2007).) The large-scale longline fleet consists mainly of vessels from Japan, the Republic of Korea, the Taiwan Province of China and, more recently, the Peoples Republic of China. Offshore fleets are either flagged by the coastal states in which they are based or are foreign fleets originating in Japan, the Taiwan Province of China or the Peoples Republic of China but based in other coastal states under charter or other business relationships.

The species-targeting characteristics of these fleets are complex (Figure 2). In the equatorial WCPO (10°N-10°S), both large-scale and offshore longliners target primarily bigeye tuna, but also take significant catches of yellowfin tuna. At higher latitudes, catches of albacore tuna tend to dominate, although catches of other tunas, swordfish and striped marlin (Tetrapturus audax) may also be locally important. Most of the vessels operating in these areas are offshore longline vessels, although large-scale longliners may also operate there seasonally. The estimated numbers of longliners in each of these categories operating in 2001-2004 are shown in Table 2.

The methodology for estimating appropriate capacity limits outlined earlier for purse seiners could be applied to the longline fleets in Table 2. The large-scale and offshore equatorial longline fleets target primarily bigeye tuna, and therefore capacity

TABLE 2

Average estimated numbers of longline vessels operating in the WCPO during 2001-2004

Fleet	Equatorial	North Pacific	South Pacific	Total
Large-scale			788	788
Offshore	2,209	1,091	647	3,947

Source: Lawson (2005)

limits consistent with bigeye stock status would be the vessel numbers reported in Table 2 divided by 1.23, *i.e.* 640 large-scale and 1,796 offshore equatorial vessels.

The offshore fleet operating in the South Pacific targets primarily albacore. Biological reference points for South Pacific albacore indicate a lightly-exploited stock, mainly because longline gear targets the oldest age groups in the population (Langley 2006). While it is unlikely that fishing mortality on these age groups could be increased to the point that MSY-based reference points were threatened, the impact of the longline fishery on the longline-exploitable abundance of South Pacific albacore has been significant—an approximate 30 percent reduction from unexploited conditions in recent years (Langley and Hampton 2005). Estimates of appropriate levels of fishing capacity are needed, mainly on economic, rather than biological, grounds. Any large increases in vessel numbers would likely reduce the average catch-per-unit-of-effort of albacore and impact profits. While there may be potential for expanded fishing effort in some areas, a conservative overall fishing capacity target, in the vicinity of the current fleet size, is probably appropriate. It should also be noted that a component of the offshore fleet in the South Pacific targets other species, *e.g.* swordfish off eastern Australia and southern bluefin tuna off New Zealand. There may well be local issues associated with these fisheries that warrant a more cautious approach to management of fishing capacity.

Offshore longliners operating in the western North Pacific are a mixture of vessels of Japan and United States targeting bigeye, yellowfin, albacore, Pacific bluefin (*Thunnus orientalis*) and swordfish. The tuna-targeting and swordfish-targeting fleets are not identified in Table 2, but it would be possible to make this classification given access to complete catch statistics. If we take an approach consistent with that taken for the equatorial fleets, an appropriate limit for the tuna-targeting component of the western North Pacific offshore fleet would be the current fleet size divided by 1.23. A formal assessment of western North Pacific swordfish is yet to be undertaken, so it is not possible to nominate a capacity limit or target for the swordfish-targeting component of the fleet.

Some of the problems of using fishing capacity limits as a means of controlling fishing mortality identified for the purse-seine fleet are also issues for the longline fleets. The multi-species nature of the fishery and differences in stock status among species poses similar difficulties as for purse seiners. In this case, however, a main target species, bigeye tuna, is the species for which there are overfishing concerns. Yellowfin tuna, a secondary target species of all longline fleets, is also estimated to be subject to overfishing; however, the assessments indicate that the impact of longline catches on yellowfin tuna stock status is minimal. North Pacific albacore tuna is considered to be at least fully exploited, but, as noted above, MSY-based reference points indicate that South Pacific albacore tuna is lightly exploited. Unlike the purse-seine fishery, it is possible to identify components of the fishery for which differential measures might be applied. Separate capacity limits could be applied to equatorial large-scale and offshore longliners (targeting bigeye tuna), and to large-scale and offshore fleets targeting albacore and other species in the North Pacific and South Pacific, based on the areas of operation of those fleets. While this is certainly not a perfect means of identifying target species, it would allow capacity measures to at least approximately address the differential stock status of the species concerned.

If fishing capacity limits were used as a means of limiting fishing mortality of bigeye tuna, the issue of "effort creep" would have to be dealt with. As with purse-seine fishing, there have been developments in longline gear technology and deployment strategies that have improved the efficiency and productivity of the vessels, and it is likely that the catchability of target species has increased as a result. Therefore, it would be necessary to periodically revise capacity or other effort-based management measures in order to limit fishing mortality.

3.3 OTHER FISHERIES

Other significant fisheries in the WCPO include the domestic fisheries in the Philippines and Indonesia, the predominantly Japanese pole-and-line fishery targeting skipjack and North Pacific albacore tuna, and troll fisheries for North Pacific and South Pacific albacore tuna. At this time there is no compelling need for management measures for the pole-and-line fishery targeting skipjack tuna or the troll fishery targeting South Pacific albacore tuna. However, there is a case for limiting the capacity of the pole-and-line and troll fisheries targeting North Pacific albacore to approximately current levels due to the fully-exploited status of that stock (Stocker 2005).

The domestic fisheries in the Philippines and Indonesia record large catches of skipjack, yellowfin and bigeye tuna, consisting mostly of small juvenile fish (Figure 3). The impact of the catches of yellowfin and bigeye tuna on population biomass is substantial (Hampton *et al.* 2005a,b); therefore, management measures to control fishing mortality by these fleets would be necessary for effective stock-wide conservation. On the basis of the 2005 stock assessments, and applying across-the-board scaling of fishing mortality to achieve MSY-based reference points, fishing mortality (and fishing effort and fishing capacity) would have to be reduced in these fisheries on the order of 20 percent from the 2001-2003 average levels. However, it is not possible to nominate specific fishing capacity or effort targets, because of a lack of data on current and historical levels of fishing capacity and effort.

3.4 FISHERY INTERACTION CONSIDERATIONS

The design of fishery management measures for the tuna fisheries of the WCPO is complicated by the exploitation of the same stocks at different stages of their life histories in different regions by different fishing methods. Management measures should take into account the potential for interaction among the different components of the fishery, and, in particular, the fact that the appropriateness of a measure in any one fishery component depends on what measures are being applied simultaneously in other components.

In the examples so far given in this paper, we have simply applied a common scaling factor to current levels of fishing effort or capacity across fishery components to derive fishing effort and capacity limits that would be consistent with stock status estimates. In so doing, the current structure of the overall fishery, in terms of spatial distribution and relative levels of fishing by different size-selective gear types, has been maintained. Implicitly, this process allocates portions of the particular effort or capacity limit to fishery components based on their recent (2001-2003 in the case of the 2005 assessments) levels. This is a relatively simple and arguably objective way to proceed, but there may well be combinations of fishing levels across the different fishery components that would result in more favourable outcomes for both the stock and the fisheries overall. This can be illustrated in the cases of yellowfin and bigeye tuna. We have determined MSY, B_{MSY} and F/F_{MSY} for hypothetical fisheries comprising single components or combinations of components of the actual fishery (Table 3). MSY is estimated to be up to 90 percent greater for yellowfin tuna and up to 33 percent greater for bigeye tuna in situations in which the catch is composed mainly of larger fish (*e.g.* hypothetical fisheries 2, 4 and 6 in Table 3). Also, for these hypothetical fisheries, F/F_{MSY} at the current levels of effort would be considerably less than 1, so overfishing would not be occurring. In contrast, if the fishery were composed only of components targeting small fish (*e.g.* hypothetical fisheries 3 and 5 in Table 3), MSY and B_{MSY} would be reduced relative to the *status quo*.

These examples serve to illustrate that stock status reference points in complex fisheries are sensitive to the size composition of the catch, which in the case of the tuna fishery of the WCPO is determined mainly by the relative mix of different size-selective gear types. The implication for fishing capacity management is that the

TABLE 3

Comparisons of *MSY*, B_{MSY} and F/F_{MSY} for hypothetical fisheries consisting of one or more components

Hypothetical fishery	Yellowfin tuna			Bigeye tuna		
	MSY	B_{MSY}	F/F_{MSY}	*MSY*	B_{MSY}	F/F_{MSY}
1. All components as in 2001-2003	1.00	1.00	1.25	1.00	1.00	1.25
2. Longline, Philippines handline	1.91	1.12	0.08	1.33	1.03	0.32
3. Purse seine FAD/flotsam sets	0.88	0.71	0.12	0.40	0.63	0.24
4. Purse seine school sets	1.55	0.98	0.06			
5. Indonesia/Philippines small-fish gears	0.61	0.95	0.29	0.77	0.99	0.53
6. Longline, Philippines handline, purse-seine school sets	1.75	1.10	0.18	1.30	1.03	0.34

MSY and B_{MSY} are expressed relative to the values obtained for the full assessment, i.e. using the actual fishery composition for 2001-2003. F/F_{MSY} is the ratio of the fishing mortality in 2001-2003 for the component(s) specified to the F_{MSY} estimated for that (those) components(s) alone.

capacity limit for one gear type is dependent on the limits specified for other gear types. In the yellowfin and bigeye tuna examples, if effort (capacity) in the purse-seine FAD/flotsam component and/or the Indonesia/Philippines small-fish component is reduced, a greater amount of effort (capacity) in the longline component could be allowed, while maintaining the overall level of fishing mortality and biomass within *MSY*-based reference points.

4. DISCUSSION

This paper has outlined a relatively simple means of aligning fishing capacity limits to estimates of stock status of the main tuna stocks comprising the WCPO tuna fishery. However, several difficulties in applying such an approach to the WCPO tuna fishery have been identified.

The multi-species nature of the purse-seine and longline fisheries and the differential status of the principal stocks make it difficult, if not impossible, for single, gear-specific capacity limits, or indeed other broadly-specified effort-based measures, to address equally the status of all the stocks simultaneously. In the longline fishery, separate consideration of longline fleets targeting bigeye tuna in the equatorial WCPO and North and South Pacific albacore tuna at higher latitudes may be reasonably effective in dealing with this problem. In the purse-seine fishery, however, differential fishing mortality of juvenile yellowfin and bigeye tuna is strongly influenced by the number of FAD/flotsam sets. Traditional capacity-based measures, such as numbers or carrying capacities of vessels are non-specific with respect to set type, and therefore would not be effective in controlling fishing mortality of bigeye and yellowfin tuna without sacrificing a large amount of the catch of skipjack tuna. The current management measure put into place by the WCPFC limits purse-seine effort to specified numbers of days of fishing and searching by purse-seine vessels. This measure also is non-specific with respect to set type, and is not likely to be effective in the long term. Measures specific to FAD/flotsam sets, or catch-based measures specific to juvenile yellowfin and bigeye tuna, will ultimately be required to achieve the dual objectives of yellowfin and bigeye conservation and the desired level of skipjack exploitation.

The problem of "effort creep" is significant for capacity and other effort-based management systems. At given levels of capacity or fishing effort, fishing mortality may increase through increased catchability, usually associated with the adoption of new technology. An additional problem for capacity limitation by vessel numbers is the potential for vessels to increase their effort per unit time by a variety of means. This was one of the factors that prompted the Parties to the Nauru Agreement to move from a limit on vessel numbers to a limit on vessel days. (The Parties to the Nauru Agreement are the Federated States of Micronesia, Kiribati, the Marshall Islands, Nauru, Palau, Papua New Guinea, the Solomon Islands and Tuvalu. Collectively, 75 percent of the purse-seine effort and catch occurs in their EEZs.) If capacity or other effort-based measures are employed, it is essential that limits are regularly reviewed and, if necessary, adjusted downwards to counter "effort creep".

The WCPO tuna fisheries are complicated by multiple jurisdictions, multiple species and multiple size-selective gear types. For any given stock, MSY and associated biological reference points are sensitive to the composition of the fishery in terms of gear types (controlling overall size composition of the catch) in particular and in some cases to spatial and seasonal distributions of catch and effort. The implication of this is that the management measures in one component of the fishery will depend on measures applied to other components. Current stock assessments typically generate reference point estimates by scaling fishing mortality with the relative mix of gear types and the spatial and seasonal distributions of the fishery maintained at recent average levels. This procedure is implicitly allocating effort (or some other management variable) consistent with recent average conditions. Other allocations among gear types, areas and seasons will have different fishery outcomes and impacts on the stocks. Such alternatives might best be considered in the context of an explicit allocation procedure.

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APPENDIX 1
Estimated catches of the main species of tunas in the WCPO.

Year	Albacore tuna				
	Longline	Pole-and-line	Purse seine	Others	Total
1950	16 740	12 863	0	0	29 603
1951	11 408	14 500	0	0	25 908
1952	22 386	41 787	154	237	64 564
1953	23 627	32 921	38	132	56 718
1954	25 877	28 069	23	38	54 007
1955	21 188	24 236	8	136	45 568
1956	18 235	42 810	0	57	61 102
1957	24 117	49 500	83	151	73 851
1958	29 702	22 175	8	124	52 009
1959	26 635	14 252	0	67	40 954
1960	31 376	25 156	0	76	56 608
1961	32 599	18 639	7	268	51 513
1962	37 279	8 729	53	191	46 252
1963	26 370	26 420	59	218	53 067
1964	26 069	23 858	128	319	50 374
1965	28 342	41 491	11	121	69 965
1966	51 317	22 830	111	585	74 843
1967	57 903	30 481	89	525	88 998
1968	45 744	16 597	267	1 123	63 731
1969	37 909	32 148	480	935	71 472
1970	47 499	24 485	279	506	72 769
1971	44 286	53 451	1 751	308	99 796
1972	44 871	49 248	86	892	95 097
1973	59 707	62 026	262	1 018	123 013
1974	39 215	69 562	193	2 001	110 971
1975	30 926	48 032	153	1 040	80 151
1976	44 457	78 992	1 147	1 367	125 963
1977	48 488	35 385	611	1 664	86 148
1978	41 982	57 745	278	7 793	107 798
1979	36 189	45 611	131	4 796	86 727
1980	42 304	43 620	323	5 639	91 886
1981	47 109	26 235	246	13 117	86 707
1982	43 355	29 518	551	15 504	88 928
1983	36 271	19 997	224	7 986	64 478
1984	30 806	26 340	3 422	14 377	74 945
1985	37 880	21 346	1 538	17 275	78 039
1986	41 702	14 179	1 619	13 114	70 614
1987	33 340	19 274	1 445	13 248	67 307
1988	41 546	07 512	1 196	27 192	77 446
1989	29 608	11 208	2 120	47 541	90 477
1990	31 822	14 244	1 953	38 543	86 562
1991	35 118	06 577	3 518	17 337	62 550
1992	45 249	15 040	4 764	19 028	84 081
1993	55 941	12 919	1 680	5 520	76 060
1994	59 974	30 591	2 222	8 315	101 102
1995	60 869	23 143	1 279	9 055	94 346
1996	61 749	22 656	256	9 463	94 124
1997	72 742	35 063	1 099	7 852	116 756
1998	79 827	27 846	1 040	8 542	117 255
1999	68 391	55 122	6 445	4 937	134 895
2000	68 422	21 886	2 161	7 707	100 176
2001	78 336	29 309	979	6 960	115 584
2002	84 692	49 596	4 072	6 413	144 773
2003	79 200	34 731	837	7 712	122 480
2004	71 337	34 797	6 932	6 562	119 628

Year	Bigeye tuna				
	Longline	Pole-and-line	Purse seine	Others	Total
1950	18 244	646	0	0	18 890
1951	12 808	729	1 095	0	14 632
1952	24 355	2 100	1 039	0	27 494
1953	23 025	2 400	619	0	26 044
1954	16 204	2 100	360	0	18 664
1955	24 749	4 000	285	0	29 034
1956	28 342	4 400	908	0	33 650
1957	35 463	5 200	49	0	40 712
1958	44 390	4 200	48	0	48 638
1959	39 789	1 700	36	0	41 525
1960	42 147	1 500	58	0	43 705
1961	36 135	1 800	63	0	37 998
1962	34 206	800	173	0	35 179
1963	40 727	1 800	6	0	42 533
1964	29 339	1 100	231	26	30 696
1965	28 392	1 300	201	29	29 922
1966	30 748	1 100	9	87	31 944
1967	32 233	2 800	60	252	35 345
1968	25 698	2 300	183	204	28 385
1969	30 245	1 700	48	62	32 055
1970	34 965	1 600	560	2 968	40 093
1971	38 359	900	690	3 243	43 192
1972	51 040	1 762	672	3 690	57 164
1973	42 412	1 258	847	4 449	48 966
1974	45 653	1 039	1 121	4 987	52 800
1975	61 488	1 334	1 054	5 212	69 088
1976	73 325	3 423	1 081	4 354	82 183
1977	72 083	3 325	1 260	5 954	82 622
1978	56 237	3 337	1 051	4 331	64 956
1979	63 704	2 540	1 680	4 966	72 890
1980	61 824	2 278	1 737	4 565	70 404
1981	45 823	2 596	3 888	5 298	57 605
1982	47 886	4 108	5 114	4 875	61 983
1983	45 270	4 055	9 109	5 320	63 754
1984	51 889	3 465	8 633	5 593	69 580
1985	57 436	4 326	6 329	6 725	74 816
1986	55 804	2 865	7 222	6 949	72 840
1987	67 818	3 134	10 926	5 852	87 730
1988	66 521	4 125	7 821	6 838	85 305
1989	62 997	4 298	12 281	7 572	87 148
1990	75 262	3 918	12 001	9 264	100 445
1991	58 185	1 991	13 271	11 270	84 717
1992	73 773	1 757	20 044	8 453	104 027
1993	64 123	2 330	13 990	7 206	87 649
1994	72 528	2 951	10 580	9 692	95 751
1995	61 137	3 776	11 487	9 666	86 066
1996	50 298	3 864	21 143	11 001	86 306
1997	63 374	3 611	37 674	10 298	114 957
1998	82 739	2 446	24 428	12 424	122 037
1999	71 632	2 176	38 152	13 184	125 144
2000	71 263	2 988	31 946	14 183	120 380
2001	73 533	2 349	28 257	13 038	117 177
2002	88 249	2 805	28 461	14 970	134 485
2003	77 849	1 786	27 238	15 481	122 354
2004	84 611	1 809	26 975	16 104	129 499

Year	Skipjack tuna				
	Longline	Pole-and-line	Purse seine	Others	Total
1950	34	33 386	0	6 483	39 903
1951	12	96 214	1 748	8 602	106 576
1952	54	78 518	3 716	10 014	92 302
1953	1	65 546	3 371	11 403	80 321
1954	0	88 073	4 534	11 554	104 161
1955	157	92 524	2 906	12 664	108 251
1956	0	91 950	2 145	13 094	107 189
1957	17	92 156	2 813	11 955	106 941
1958	0	131 441	10 698	15 244	157 383
1959	33	145 447	16 941	14 853	177 274
1960	0	70 428	3 728	15 782	89 938
1961	0	127 011	11 693	18 032	156 736
1962	4	152 387	11 674	17 559	181 624
1963	0	94 757	9 592	18 354	122 703
1964	5	137 106	25 006	20 668	182 785
1965	11	129 933	4 657	20 459	155 060
1966	52	215 600	10 949	22 654	249 255
1967	124	168 846	10 931	24 621	204 522
1968	83	162 379	7 587	24 870	194 919
1969	154	168 084	5 057	30 008	203 303
1970	1 669	197 873	7 534	35 181	242 257
1971	1 526	180 945	13 769	32 361	228 601
1972	1 565	172 827	18 079	45 193	237 664
1973	1 896	253 217	19 271	53 929	328 313
1974	2 149	289 202	11 136	53 711	356 198
1975	1 934	218 271	13 579	54 553	288 337
1976	2 109	276 582	23 604	55 276	357 571
1977	3 142	294 641	35 320	69 473	402 576
1978	3 249	331 401	35 535	79 184	449 369
1979	2 208	285 859	59 367	65 412	412 846
1980	640	333 457	79 235	45 193	458 525
1981	800	294 292	90 206	50 421	435 719
1982	1 068	262 244	169 745	52 929	485 986
1983	2 147	299 762	319 025	56 658	677 592
1984	877	379 474	322 792	46 990	750 133
1985	1 210	250 010	293 744	55 486	600 450
1986	1 468	336 695	349 795	60 861	748 819
1987	2 363	262 466	363 206	53 265	681 300
1988	1 980	301 031	488 046	48 395	839 452
1989	2 580	289 706	472 376	50 508	815 170
1990	1 299	224 592	584 302	70 170	880 363
1991	1 549	282 397	755 019	67 509	1 106 474
1992	1 156	226 589	721 192	88 681	1 037 618
1993	1 069	270 671	569 364	74 055	915 159
1994	1 519	231 385	714 132	67 364	1 014 400
1995	1 415	266 736	698 570	89 398	1 056 119
1996	4 699	230 576	706 335	85 381	1 026 991
1997	4 819	250 685	634 417	86 527	976 448
1998	5 023	287 945	912 728	98 687	1 304 383
1999	4 232	293 269	760 951	98 477	1 156 929
2000	5 472	287 842	833 325	110 538	1 237 177
2001	5 447	228 336	812 499	89 823	1 136 105
2002	4 125	224 146	963 865	92 030	1 284 166
2003	4 543	247 291	941 261	101 970	1 295 065
2004	4 900	245 353	1 015 517	104 482	1 370 252

Year	Yellowfin tuna				
	Longline	Pole-and-line	Purse seine	Other	Total
1950	12 844	799	0	08 919	22 562
1951	8 862	900	938	10 415	21 115
1952	17 453	2 595	2 565	10 539	33 152
1953	23 139	5 228	1 260	10 871	40 498
1954	22 662	4 268	4 001	11 763	42 694
1955	22 800	3 983	2 944	12 633	42 360
1956	25 336	4 399	0 724	12 818	43 277
1957	41 911	1 669	1 496	13 481	58 557
1958	41 804	2 934	3 338	14 682	62 758
1959	42 802	4 119	4 316	15 673	66 910
1960	53 617	01 872	01 438	15 919	72 846
1961	52 717	03 259	02 777	17 044	75 797
1962	58 049	04 225	06 975	18 150	87 399
1963	55 673	02 071	02 277	18 676	78 697
1964	48 000	05 073	03 647	20 183	76 903
1965	49 238	03 434	03 752	20 958	77 382
1966	65 973	02 192	05 844	23 409	97 418
1967	36 799	03 125	03 428	26 303	69 655
1968	47 467	02 706	07 106	26 084	83 363
1969	51 939	02 714	03 857	26 609	85 119
1970	55 806	02 674	07 811	30 933	97 224
1971	57 766	02 866	09 150	32 894	102 676
1972	61 175	07 465	10 002	37 506	116 148
1973	62 291	07 458	14 798	43 828	128 375
1974	58 116	06 582	17 130	49 441	131 269
1975	69 462	07 801	12 893	51 029	141 185
1976	77 570	17 186	14 976	42 766	152 498
1977	94 414	15 257	15 515	58 070	183 256
1978	110 329	12 767	13 292	39 401	175 789
1979	109 043	11 638	28 163	49 565	198 409
1980	122 444	13 168	31 849	47 758	215 219
1981	94 665	19 269	59 463	54 082	227 479
1982	84 988	13 835	73 738	49 477	222 038
1983	86 187	13 266	105 773	53 872	259 098
1984	73 036	13 558	111 474	57 537	255 605
1985	76 117	18 156	100 425	66 686	261 384
1986	65 014	13 074	105 901	69 134	253 123
1987	76 695	13 243	155 400	60 659	305 997
1988	88 767	13 433	95 536	69 337	267 073
1989	68 474	15 169	159 263	73 824	316 730
1990	75 522	13 103	175 432	93 998	358 055
1991	62 314	12 921	214 488	111 177	400 900
1992	73 271	15 225	252 062	79 038	419 596
1993	67 173	12 698	238 477	71 183	389 531
1994	75 436	13 742	214 278	95 588	399 044
1995	81 113	15 050	184 475	97 468	378 106
1996	77 827	15 492	114 011	107 390	314 720
1997	70 656	12 362	246 382	102 189	431 589
1998	68 636	13 110	263 230	122 025	467 001
1999	61 384	13 817	212 185	134 007	421 393
2000	79 791	13 745	196 339	143 176	433 051
2001	75 497	12 163	210 055	129 293	427 008
2002	75 290	13 357	183 902	146 315	418 864
2003	74 359	12 039	205 168	155 108	446 674
2004	71 483	11 855	171 098	158 295	412 731

Year	Total tuna				
	Longline	Pole-and-line	Purse seine	Other	Total
1950	47 862	47 694	0	15 402	110 958
1951	33 090	112 343	3 781	19 017	168 231
1952	64 248	125 000	7 474	20 790	217 512
1953	69 792	106 095	5 288	22 406	203 581
1954	64 743	122 510	8 918	23 355	219 526
1955	68 894	124 743	6 143	25 433	225 213
1956	71 913	143 559	3 777	25 969	245 218
1957	101 508	148 525	4 441	25 587	280 061
1958	115 896	160 750	14 092	30 050	320 788
1959	109 259	165 518	21 293	30 593	326 663
1960	127 140	98 956	5 224	31 777	263 097
1961	121 451	150 709	14 540	35 344	322 044
1962	129 538	166 141	18 875	35 900	350 454
1963	122 770	125 048	11 934	37 248	297 000
1964	103 413	167 137	29 012	41 196	340 758
1965	105 983	176 158	08 621	41 567	332 329
1966	148 090	241 722	16 913	46 735	453 460
1967	127 059	205 252	14 508	51 701	398 520
1968	118 992	183 982	15 143	52 281	370 398
1969	120 247	204 646	9 442	57 614	391 949
1970	139 939	226 632	16 184	69 588	452 343
1971	141 937	238 162	25 360	68 806	474 265
1972	158 651	231 302	28 839	87 281	506 073
1973	166 306	323 959	35 178	103 224	628 667
1974	145 133	366 385	29 580	110 140	651 238
1975	163 810	275 438	27 679	111 834	578 761
1976	197 461	376 183	40 808	103 763	718 215
1977	218 127	348 608	52 706	135 161	754 602
1978	211 797	405 250	50 156	130 709	797 912
1979	211 144	345 648	89 341	124 739	770 872
1980	227 212	392 523	113 144	103 155	836 034
1981	188 397	342 392	153 803	122 918	807 510
1982	177 297	309 705	249 148	122 785	858 935
1983	169 875	337 080	434 131	123 836	1 064 922
1984	156 608	422 837	446 321	124 497	1 150 263
1985	172 643	293 838	402 036	146 172	1 014 689
1986	163 988	366 813	464 537	150 058	1 145 396
1987	180 216	298 117	530 977	133 024	1 142 334
1988	198 814	326 101	592 599	151 762	1 269 276
1989	163 659	320 381	646 040	179 445	1 309 525
1990	183 905	255 857	773 688	211 975	1 425 425
1991	157 166	303 886	986 296	207 293	1 654 641
1992	193 449	258 611	998 062	195 200	1 645 322
1993	188 306	298 618	823 511	157 964	1 468 399
1994	209 457	278 669	941 212	180 959	1 610 297
1995	204 534	308 705	895 811	205 587	1 614 637
1996	194 573	272 588	841 745	213 235	1 522 141
1997	211 591	301 721	919 572	206 866	1 639 750
1998	236 225	331 347	1201 426	241 678	2 010 676
1999	205 639	364 384	1017 733	250 605	1 838 361
2000	224 948	326 461	1063 771	275 604	1 890 784
2001	232 813	272 157	1051 790	239 114	1 795 874
2002	252 356	289 904	1180 300	259 728	1 982 288
2003	235 951	295 847	1174 504	280 271	1 986 573
2004	232 331	293 814	1 220 522	285 443	2 032 110

Measuring fishing capacity in tuna fisheries: Data Envelopment Analysis, industry surveys and data collection

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ABSTRACT

This paper addresses Objective B of the FAO Methodological Workshop on the Management of Tuna Fishing Capacity, which is "to determine the feasibility of, (1) routinely collecting input data for the Data Envelopment Analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization." Data envelopment analysis (DEA) derives a deterministic production frontier describing the most technically efficient combination of outputs, given the state of fishing technology, the fish stock and unrestricted variable inputs. Within the context of measuring fishing capacity to allow for DEA to be undertaken, it is necessary, at the very least, to obtain a data set detailing fixed inputs (fixed physical characteristics of individual vessels) to the fishery and the associated outputs (catches) of those vessels. Such data are available for the eastern and the western and central Pacific Ocean, but not for the Atlantic and Indian Oceans. The paper also addresses the potential to conduct industry surveys in order to obtain estimates of tuna fishing capacity utilization and concludes that, while it may be feasible in principle, it may be difficult in practice.

1. INTRODUCTION

This paper addresses Objective B of FAO Methodological Workshop on the Management of Tuna Fishing Capacity, which is "to determine the feasibility of, (1) routinely collecting input data for the Data Envelopment Analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization."

In Section 2 of the paper an overview of the concepts of capacity and capacity utilization are provided. Section 3 provides background to DEA methodology, requirements for DEA, current availability of data for major industrial tuna fisheries that are suitable for DEA and the feasibility of routinely collecting such data. Section 4 provides background information on industrial surveys of capacity utilization and the feasibility of employing such surveys to measure tuna fishing capacity utilization.

2. CAPACITY AND CAPACITY UTILIZATION

Capacity is a short-run concept, for which firms and industry face short-run constraints, such as the stock of capital or other fixed inputs, existing regulations, the state of technology and other technological constraints (Morrison 1985). Capacity is defined in terms of potential output. This potential output can be further defined and measured in accordance with either a technological-economic approach or an economic optimization approach based directly on microeconomic theory (Morrison 1985).[1] What distinguishes the two notions of capacity is how the underlying economic aspects are included to determine the capacity output.

In either approach, capacity utilization (CU) is simply actual output divided by capacity output (Morrison 1985).[2] In the technological-economic approach, a CU value of less than 1 implies that firms have the potential for greater production without having to incur major expenditures for new capital or equipment (Klein and Summers 1966).

This paper, Reid *et al* (2005), Squires *et al* (2003), Kirkley and Squires (1999), the 1998 FAO Technical Working Group (FAO 1998) and the 1999 FAO Technical Consultation (FAO 2000) focus on the technological-economic measures of capacity, because the paucity of cost data in most fisheries militates against estimation of cost or profit functions to derive economic measures of capacity and capacity utilization. Similarly, the technological-economic approach is the one used by the US Federal Reserve Board (Corrado and Mattey 1997) and in most other countries to monitor capacity utilisation throughout the economy.

The technological-economic capacity of a firm can be defined following Johansen's (1968, p. 52) definition of plant capacity as, "... the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted". Färe (1984) provides a formal proof and discussion of plant capacity.[3]

Capacity output thus represents the maximum production that fixed inputs are capable of supporting. This concept of capacity conforms to that of a full-input point on a production function, with the qualification that capacity representing a realistically sustainable maximum level of output, rather than some higher unsustainable short-term maximum (Klein and Long 1973). In practice, this approach gives maximum potential output, given full utilization of the variable inputs under normal operating conditions because the data used reflect normal operating conditions and existing market, resource stock and environmental conditions.[4] This approach gives an endogenous output, and incorporates the firm's *ex ante* short-run optimization behaviour for the production technology, given full utilization of the variable inputs under normal operating conditions.

The definition and measurement of capacity in fishing and other natural resource industries face a unique problem because of the stock-flow production technology, in which inputs are applied to the renewable natural resource stock to produce a flow of output. For renewable resources, capacity measures are contingent upon the level of the resource stock. Capacity is, therefore, the maximum yield in a given period of time that can be produced, given the capital stock, regulations, current technology and state of the resource (FAO 1998, Kirkley and Squires 1999). Nonetheless, annual climate-driven ocean variability is clearly a key factor affecting fisheries. Monsoon and El Nino-Southern Oscillation events provide clear examples because the distribution and catchability of fish varies. As a consequence, and owing to annual changes in the size and species and age mix of the resource stocks, the target level and capacity output from the stock-flow production process can vary annually, and even seasonally, when there are strong seasonal effects.

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[1] In the economics approach, capacity can be defined as the output pertaining to one of two economic optima: (1) the tangency of the short- and long-run average cost curves (Chenery 1952, Klein 1960, Friedman 1963), so that the firm is in long-run equilibrium with respect to its use of capital, or (2), the tangency of the long-run average cost curve with minimum short-run average total cost curve (Cassel 1937, Hickman 1964).

[2] See also Greboval (2003).

[3] For further basic discussion, see also Färe, Grosskopf, and Kokkelenberg (1989). For further discussion on the application of plant capacity to fisheries, *i.e.* the technological-economic notion of fishing capacity, see Kirkley and Squires (1999), Kirkley, Morrison Paul and Squires (2002, 2004), and Pascoe *et al.* (2003).

[4] Klein and Long (1973, p. 744) state that, "Full capacity should be defined as an attainable level of output that can be reached under normal input conditions without lengthening accepted working weeks, and allowing for usual vacations and for normal maintenance." The US Bureau of the Census survey uses the concept of practical capacity, defined as "the maximum level of production that this establishment could reasonably expect to obtain using a realistic employee work schedule with the machinery and equipment in place" and assuming a normal product mix and down time for maintenance, repair and cleanup.

An additional factor that is important to consider is the source of variations in the level of technical efficiency at which a vessel operates. Pascoe and Coglan (2002) found that differences in vessel characteristics explained about one third of the variation in technical efficiency of English Channel trawlers, and attributed the remainder to unmeasurable characteristics, such as skill of the captains and differences in technology that could not be quantified. Other studies (*e.g.* Kirkley, Squires and Strand 1998 and Squires and Kirkley 1999) have also suggested that much of the difference in efficiency among vessels may be owing to differences in skill of the captains. As such, in this study, where data permits, fishing capacity is estimated under two different measures. First, as discussed previously, it is estimated under full variable input utilization and maximum technical efficiency. Second, it is estimated under full variable input utilization, but with current levels of technical efficiency. The latter was done to try to account for variations in skill levels of the captains in deriving estimated capacity output levels; it, in effect, measures capacity utilization purged of the effects of technical efficiency.

In fisheries and other renewable resource industries, excess capacity is often defined relative to some biological or bio-socio-economic reference point, which accounts for sustainable resource use and a target resource stock size. Excess capacity, in a technological-economic approach, can be defined as the difference between capacity output and the target level of capacity output, such as maximum sustainable yield or the catch rate corresponding to the fishing mortality of an alternative harvest (FAO 1998). The target level of capacity output was defined by the 1998 FAO Technical Working Group as, "Target fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized while satisfying fishery management objectives designed to ensure sustainable fisheries ..."(FAO 1998, p. 11)[5] The 1999 FAO Technical Consultation on measuring fishing capacity reached a similar conclusion (FAO 2000). The target fishing capacity catch can be specified as, for example, maximum sustainable yield (MSY) or maximum economic yield (MEY).

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[5] Fishing capacity is generally defined by FAO (1998, 2000) as follows:

Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology. Fishing capacity is the ability of a vessel or fleet of vessels to catch fish, *i.e.* $Y_C = Y(E_C, S)$.

In this general definition, Y_C denotes current yield/catch, E_C denotes current effort, and S denotes stock size (biomass). Fishing capacity thus represents the maximum amount of fish caught by a fleet fully utilizing its variable economic inputs under normal operating conditions, given the fleet's capital stock (vessels gear and equipment, including fish-aggregating devices), biomass and harvesting technology. Normal operating conditions refers to those operating conditions faced by fishing vessels in the normal conditions of the periods in which they operate.

3. THE FEASIBILITY OF ROUTINELY COLLECTING INPUT DATA FOR DATA ENVELOPMENT ANALYSIS (DEA)

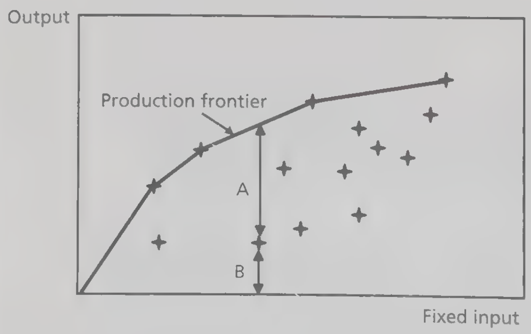
3.1 Data Envelopment Analysis (DEA)

The DEA approach derives a deterministic production frontier describing the most technically efficient combination of outputs, given the state of fishing technology, the fish stock and unrestricted variable inputs. Färe (1984) introduced this methodology as a means of measuring the technological-economic concept of capacity and CU for manufacturing firms, and it was further developed by Färe, Grosskopf and Kokkelenberg (1989). Kirkley and Squires (1999) proposed DEA as a useful approach for assessing capacity in fisheries. The DEA approach distinguishes between variable and fixed factors, and allows for multiple outputs and variable returns to scale.

The DEA approach calculates capacity output, given that the variable factors are unbounded and the fixed factors, environmental parameters, such as the resource stock and oceanic conditions, and state of technology constrain output. Capacity output corresponds to the output that could be produced, given full and efficient utilisation of variable inputs and given the constraints imposed by the capacity base–the fixed factors, the state of technology, environmental conditions and resource stock. In practice, because the data reflect both technological and economic decisions made by firms, the variable inputs correspond to full and efficient utilization under normal operating conditions

The use of DEA to estimate fishing capacity output and capacity utilization is illustrated in Figure 1. DEA, using the observed landings for different-sized vessels and a measure of the capital stock or fixed inputs, such as gross registered tonnage (GRT), determines the output or landings that are the greatest for any given vessel size, assuming that variable inputs are fully utilized (variable inputs are thereby unconstrained) under normal operating conditions, where normal operating conditions are reflected in the data. DEA estimates a frontier or maximum landings curve, as determined by the best-practice vessels, which represents fishing capacity output. The landings directly on the best-practice production frontier represent full capacity utilization (CU = 1). When a vessel produces at less than full capacity, as represented by an output lying below the frontier in Figure 1, the capacity utilization is less than 1. In Figure 1, therefore, B represents the size of landings, A denotes the excess capacity (*vis-à-vis* observed production), A + B denotes capacity output, and the ratio A/(A + B) represents capacity utilization, so that CU < 1 in this case. The production frontier(also called the reference technology), established by the best-practice vessels (the ones on the frontier) and estimated by DEA, gives capacity output, given the fixed inputs or capacity base, the states of technology and the environment and the resource stocks, provided that the variable inputs (fishing effort) are fully utilized under normal operating conditions. The production frontier gives technically efficient output, given the fixed inputs, states of technology and the environment, and resource stocks when the variable inputs are utilized at the observed levels. Hence, the difference between capacity output and technically efficient output is that variable inputs are fully utilized in the former and are utilized at the observed levels (which could be fully utilized) in the latter.

FIGURE 1
Data Envelopment Analysis



Alternative methods for measuring capacity and capacity utilization have been proposed, most notably duality-based measures using cost, profit or revenue functions (Morrison 1985, Squires 1987, Segerson and Squires 1990, 1993, 1995). Unlike duality-based econometric estimates such as cost, profit or revenue functions, DEA does not impose an underlying functional form. Unlike the cost, profit or revenue function approach, DEA estimates primal measures of capacity in a multiple-product environment without imposing separability assumptions on the outputs (Segerson and Squires 1990). DEA can be used when prices are difficult to define, behavioural assumptions, such as cost minimization, are difficult to justify or cost data are unavailable.

The DEA approach has limitations. First, it is a non-statistical approach, which makes statistical tests of hypotheses about structure and significance of estimates difficult to perform. Second, because DEA is non-statistical, all deviations from the frontier are assumed to be to the result of inefficiency. Third, estimates of capacity and capacity utilization may be sensitive to the particular data sample (a feature shared by the dual cost, profit or revenue function approach).

3.2 Data requirements

Within the context of measuring fishing capacity to allow for DEA to be undertaken, it is necessary, at the very least, to obtain a data set detailing fixed inputs (fixed physical characteristics of the vessels) to the fishery and the associated output (catch). The data on the physical characteristics could include, among other attributes, GRT, well capacity, engine horsepower and/or freezing capacity per day. While it is not necessary that such data be obtained at a vessel level it is necessary that the data be disaggregated to a reasonable degree so as to allow for a "sufficient" number of observation points.[6] Obviously the greater the disaggregation at which the data are available, the better the estimate obtained from any DEA will be. It is also necessary that the two data sets can be linked, that is, if data are, for example, obtained at the vessel level, then to conduct DEA it is necessary that the data on the physical characteristics of each vessel can be associated with its catch data.

To allow for consideration of skill of the captains in estimating fishing capacity (that is, purging measured capacity for variations in skill of different captains) it is necessary to also have a data set detailing variable inputs, such as, for example, fishing or searching days, number of hooks set and/or fuel consumption. It is also necessary that these data can be directly associated with the fixed input and output data sets at whatever level of disaggregation the analysis is conducted.

3.3 Data availability

3.3.1 Purse seine fisheries

Reid *et al.* (2005) conducted a DEA of global tuna purse-seine fishing capacity by ocean area (eastern Pacific Ocean (EPO), western and central Pacific Ocean (WCPO), Indian Ocean and Atlantic Ocean), and the following observations can be drawn from this analysis and associated work. With regard to the EPO and WCPO, it was possible to obtain data at the vessel level that could be used to represent fixed inputs, variable inputs and outputs *and* to link these data sets. The data for the EPO were obtained from the Inter-American Tropical Tuna Commission (IATTC). The data for the WCPO were obtained from the Secretariat for the Pacific Community (SPC), with the exception of data for the Japanese fleet, which were obtained from the Fisheries Research Agency (FRA) of Japan. The reason for this was that the Japanese purse-seine fleet do not provide data relating to fishing activities outside the Exclusive Economic Zones (EEZs) of members of the SPC (*i.e.* the high seas and Japan's EEZ).

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[6] An "insufficient" number of observations gives an estimated piece-wise linear frontier with more and/or longer linear segments and a less accurate measure of capacity output. Without enough "kinks" (from shorter and a larger number of segments) in the piece-wise linear frontier, the distance from an observed output to the frontier, where the observed frontier gives the capacity output, is reduced.

Reid *et al.* (2005) found that data sets that could be used to represent fixed inputs, variable inputs and output at a vessel level are also available for the Indian and Atlantic oceans. However, it was not possible to link these data, nor were the organizations holding the data prepared to undertake the work to do so. As a consequence, Reid *et al.* had to use highly-aggregated data in estimation of purse-seine fishing capacity in these areas.

3.3.2 Longline and pole-and-line fisheries

Reid, Kirkley and Squires (2004) examined the feasibility of applying DEA to measure fishing capacity of the global longline and pole-and-line fleets, given available data, and made the following observations:

In the Indian Ocean IOTC [Indian Ocean Tuna Commission] provides two sets of data which are of interest. First, is the catch data by fishing method. From this we can ascertain the level of catch taken by longline vessels and pole and line vessels (baitboats) in the Indian Ocean and within smaller areas within the Indian Ocean over a significant period. Second, is the IOTC positive list which contains a list of vessels and some of their characteristics that are currently on the IOTC positive list. These two data are in themselves insufficient to conduct DEA as, as was noted in the conduct of the purse seine fishing capacity DEA, the positive list is not available as a time series nor is it a reasonable proxy of the actual number of vessels operating in the fishery. Given this attempts were made to obtain data from national fisheries agency on their long line and pole and line fleets and catches. The only response from these request were from Indonesia and Japan with Indonesia providing some data from a proportion of their longline fleet. Japan indicated that it may be possible to obtain some data with the permission of its fishing industry. Attempts were also made to construct a time series of vessel numbers from other sources such as IOTC publications. Given these factors, at this stage it appears that there is not sufficient data to under any meaningful DEA of longline or pole and line fishing capacity in the Indian Ocean.

The story is similar in the Atlantic and Eastern Pacific Ocean, although a more thorough search is required in the case of the Eastern Pacific Ocean.

For the Western and Central Pacific Ocean vessel level data is available in terms of both vessel characteristics and catch. However, the catch data does not in most case include catches taken outside of the waters of member countries of the Secretariat of the Pacific Community (SPC). Nonetheless, the data should be sufficient to allow for a meaningful DEA to be conducted.

Overall it appears that there is not sufficient data to allow for a meaningful DEA to be conducted that would provide for better estimates of global longline and pole and line fishing capacity than those provided by other papers presented at this meeting.

An informal meeting on DEA held in conjunction with the 17th meeting of the Standing Committee on Tuna and Billfish of the Oceanic Fisheries Programme of the SPC in August 2004 considered, among other issues, conducting DEA to estimate global longline fishing capacity, and reached the following conclusion:

> … the data representing the minimum data requirements for Project 2 [measurement of longline capacity] are available only for the Japanese industrial longline fishery. Even if such data were collected for other major industrial longline fleets, the DEA can be carried out only at a very basic level and no significantly better information would be expected than input measurements presented at the 2nd TAC [Technical Advisory Committee] for these fleets. (FAO 2004).

3.4 Summary

It appears that a reasonable set of data of fixed inputs (vessel characteristics) can be obtained for larger scale purse-seine, longline and pole-and-line fleets and, in some cases, smaller-scale vessels.

However, this is not the crux of the problem that is faced in trying to conduct a DEA at a level of disaggregation from which worthwhile results can be obtained. The problem is associating the input data with variable input (effort) and output (catch) data at anything but a fishery level. Thus, the problem is often not the availability of fixed input data but the availability of the data in an appropriate form for DEA (*i.e.* cases for which catches can be associated with a particular vessel or subset of vessels and the characteristics of the vessel or sub-set of vessels are available). The answer to the question as to whether it is technically feasible to obtain fixed input data is, in many cases, yes; however, the real question is whether regional fishery management organizations (RFMOs) and others are prepared to provide disaggregated data that allow catches to be associated with particular vessels, or at least a reasonably disaggregated grouping of vessels. From previous experience, the answer to this latter question is mixed. There are also other problems, such as, for example, obtaining a full set of variable input and output data for the WCPO for longliners of "distant-water fishing nations" in areas outside of the Exclusive Economic Zones (EEZs) of SPC members. This means that, while vessel characteristics data can be obtained, they can be associated only with the variable inputs and outputs of a vessel within the EEZs of SPC members, rather than for that vessel's entire operations. The question then arises as to whether it would be possible to collect such data for conducting a DEA. This is a question that can be answered only by the flag states. As such, the issue at hand is not the feasibility of collecting fixed input (vessel characteristic) data, but of collecting vessel level variable input (effort) and output (catch) data for the entire operations of vessels and whether this can be associated with the fixed input (vessel characteristic) data.

4. FEASIBILITY OF PERFORMING INDUSTRY SURVEYS OF TUNA FISHING CAPACITY UTILIZATION

Surveys of plant capacity and its utilization for many industries are routinely conducted in many countries that are members of the Organisation for Economic Co-operation and Development (OECD). These surveys could be adapted to tuna fishing. A pilot project to determine feasibility could begin with tuna purse-seine vessels because there are fewer tuna purse-seine vessels than longline or pole-and-line vessels, and because DEA studies of fishing capacity of purse-seine vessels have been conducted that can serve as a basis for comparison. If these surveys are deemed feasible and desirable, the approach could be extended to the other gear types.

4.1 Two basic survey approaches

Two basic approaches are possible on an annual basis. The first approach directly surveys individual vessels for their annual fishing capacity, capacity utilization and vessel size (well capacity, GRT, engine power, *etc.*), where fishing capacity is defined by potential catch or output following FAO (1998, 2000). An entire fleet (or some other well-defined unit) or a sample from the fleet (or well-defined unit) could be surveyed. Similarly, direct surveys of full production capability or full capacity production—plant capacity—and the rate of capacity utilization are routinely conducted in many OECD countries by central banks, central government statistical agencies and the like. These surveys query plants directly about their current levels of production and the production that could have been produced if the plant were operating at full capacity, *i.e.* its capacity output or plant capacity.[7] These concepts of capacity and capacity utilization correspond directly to the FAO concepts of fishing capacity and capacity utilization. This approach is discussed more fully below.

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[7] Plant capacity or full production capability, which is comparable to a fishing vessel's fishing capacity, as defined by the FAO and to the Johansen (1968) definition, is evaluated by its capacity output in a manner exactly parallel to the FAO definition. The plant's capacity base is not assessed by its area (square meters) or volume (cubic meters), but by its potential production under normal and realistic operating conditions. Capacity of elevators, theaters and passenger vessels is similarly assessed by its potential output or number of persons carried under normal and realistic operating conditions (and subject to safety considerations).

The second approach would assess annual fishing capacity and its utilization by surveying vessels for their actual and potential fishing effort, as measured by some measure of fishing time (*e.g.* days fished), and their capital stock, as measured by some proxy such as well capacity, GMT (or net registered tonnage) or horsepower.[8] This approach assesses what was called "Physical Capacity" by the 1999 FAO Technical Consultation on the Measurement of Fishing Capacity (FAO 2000), and which corresponds to that used by the European Union (Lindebo 2003).[9] [10] This measure is discussed more fully below.

4.2 Direct surveys of the FAO measure of fishing capacity[11]

The FAO definition of fishing capacity corresponds to the measures of plant capacity—full production capability, such as that used by the US Department of Commerce and the US Census Bureau (see the Appendix). These measures are output-oriented, as is the case for the FAO definition.

The US Department of Commerce and US Census Bureau survey of plant capacity (*i.e.* full production capability) and plant capacity utilization for many industries asks about the market value (*i.e.* market revenue) of the products (emphasis added):

1. the actual products produced;
2. the **value** of products that could have been produced if the plant was operating at full capacity in the **fourth quarter**;
3. the **value** of products that could have been produced if required in a **national emergency**.

To adapt this approach to tuna fisheries, several unique features of tuna vessels would have to be accommodated:

1. Only the first two of the three levels of operating capability of a plant are germane for surveys of tuna vessels; *i.e.* actual and full capacity production. National emergency is germane to the question at hand.
2. Tuna vessels correspond to plants, so that the focus is on vessels, rather than on firms or companies (in cases for which a tuna firm may own more than one vessel).
3. Survey vessels for their catches of all tuna species, in metric tons, rather than survey market value of the catch or revenue.
4. The catches of individual tuna species would be summed to total catch (in metric tons), according to the catch species mix during the period of the survey. (This corresponds to an industrial plant producing multiple products.)
5. The fourth-quarter focus could be broadened to the entire year, owing to the seasonality of fisheries and the importance of a more accurate measure of capacity to manage a renewable resource.

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[8] This second approach is fundamentally a measure of capital utilization, and the extrapolation from fishing effort to fishing capacity and capacity utilization requires the following assumptions: (1) fish stocks are constant (so that increases in potential fishing effort generate constant catch rates); (2) there is a single capital stock; (3) all variable inputs are in fixed proportions; (4) constant returns to scale (a proportional increase in all inputs leads to a proportional increase in output or catch) (Berndt 1990, Kirkley and Squires 1999).

[9] Changes in the quality of the capital stock over time are not captured by this measure. For example, technical progress which is embodied in the capital stock, such as vessel electronics or improved brailing systems, is not captured.

[10] Fishing effort, as a measure of time in a flow of capital services, in technical economics terms, is an important component of capital utilization, rather than capacity utilization. Capital utilization in formal economics is defined as the ratio of the flow of services from the capital stock to the stock (Hulten 1990).

[11] We thank Joseph Terry for calling our attention to this website.

Surveying vessels for their actual and full production capability catches in volume units (metric tons), rather than value units (US dollars, yen, Euros, *etc.*) more closely corresponds to the biological management of fisheries and abstracts from exchange rate fluctuations when comparing across flag states and fisheries.

Based on the definition of full production capability in the Appendix, the following assumptions would be specified:

Full production capacity or capability is defined as the maximum level of production that this establishment could reasonably expect to attain under **normal** and **realistic** operating conditions, fully utilizing the machinery and equipment in place. The following factors are to be considered in estimating market value at full production capacity or capability:

- Assume **only** the machinery, gear and equipment in place and ready to operate will be utilized. Do not include facilities or equipment that would require extensive reconditioning before they can be made operable.
- Assume **normal** downtime and time in port for maintenance, repair, cleanup, fueling, provisioning, assembling crewmembers, off-loading and other such activities. If full production requires additional time in port for repairs, drydocking, refitting, *etc.*, then appropriate downtime should be considered in the estimate.
- Assume number of shifts, hours of vessel operations and overtime pay that can be sustained under **normal** conditions and a **realistic** work schedule.
- Assume crewmembers, other labour, fuel, provisions, gear, materials, utilities, *etc.* are fully available.
- Assume a species mix that was **typical** or representative of production during the time period of concern. If a vessel is subject to short-run variation, then assume the species mix of the current period.
- Assume methods of fishing (unassociated schools, flotsam, drifting fish-aggregating devices, dolphins, *etc.*) that are typical or representative of production during the time period of concern.
- Assume biological resource abundance and environmental conditions, such as weather, sea-surface temperature, currents, *etc.*, that are typical or representative during the time period of concern.
- Do not assume increased use of productive facilities outside the vessel for services (such as at-sea off-loading if off-loading at shore-based operations is the usual case) in excess of the proportion that would be normal during the fourth quarter.

The vessel's capacity utilization rate should be based on a capacity catch and species mix that the vessel could have sustained under **normal**, not emergency, conditions.

4.3 Surveys of physical capacity: potential fishing effort

Physical capacity, in terms of potential fishing effort, is defined by FAO (2000, Appendix E, page 26). Vessel units (VU) were defined as measures of the capital stock, such as boat numbers, GRT, carrying capacity, *etc.* Effort units (EU) were defined as a measure of flow of capital services, such as sum (days fished*VU). Potential effort units (PEU) were defined as effort if all capacity was fully utilized, such as sum (maximum days fished*VU). Capacity utilization was then defined as $CU_t = EU_t/PEU_t$, where $0 < CU_t < 1$.

Surveys to establish potential fishing effort would be similar to those for plant capacity or full production capability. The unique features would be questions pertaining to the potential fishing effort if there were not any constraints, such as those imposed by weak markets, regulations, breakdowns in equipment, difficulties in finding captains or other crewmembers, issues related to vessel monitoring systems or access rights and so forth. Surveys would also ask for actual time spent away from port (days absent) and for the preferred measures of vessel size (well capacity, carrying capacity, registered tonnage, length, *etc.*).

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APPENDIX
SURVEYS OF PLANT CAPACITY UTILIZATION IN THE UNITED STATES

Surveys of plant capacity utilization for many industries are routinely conducted in many OECD countries. In the United States, the Survey of Plant Capacity Utilization for many industries is conducted jointly by the US Census Bureau, the Federal Reserve Board and the Defense Logistics Agency. The US Census Bureau website, http://www.census.gov/cir/www/mqc1pag2.html, contains considerable information on this subject.

The survey collects data for the fourth quarter, and includes operational status (sold, leased, permanently ceased), number of days and hours worked, number of workers, number of shifts worked and three levels of operating capability of the plant during the fourth quarter: (1) the market value of actual goods produced; (2) the value of products that could have been produced if the plant was operating at full capacity during the fourth quarter; and (3) the value of products that could have been produced if required in a national emergency.

The following is a copy from selected text of the US Census Bureau website report. Boldface type is used as it appears in the instructions.

Seasonal Operations:

a. If this plant is usually temporarily idle during the fourth quarter *due to seasonal factors*, report as instructed for idle plants.

b. If this plant was not temporarily idle during the fourth quarter, but its operations vary substantially from quarter to quarter, *due to seasonal factors*, complete items 2 through 5 (2. Value of Production, 3. Work Patterns of Fourth Quarter Operations, 4. Fourth Quarter Actual Operations vs. Full Production Capability, 5. National Emergency Production), and report full production and national emergency production capabilities based on the plant's **peak** quarterly production during the year.

Full Production Capability:

Full production capacity or capability is defined as the maximum level of production that this establishment could reasonably expect to attain under **normal** and **realistic** operating conditions fully utilizing the machinery and equipment in place. The following factors are to be considered in estimating market value at full production capacity or capability:

- Assume **only** the machinery and equipment in place and ready to operate will be utilized. Do not include facilities or equipment that would require extensive reconditioning before they can be made operable.
- Assume **normal** downtime, maintenance, repair, and cleanup. If full production requires additional shifts or hours of operation, then appropriate downtime should be considered in the estimate.
- Assume number of shifts, hours of plant operations, and overtime pay that can be sustained under **normal** conditions and a **realistic** work schedule.
- Assume labor, materials, utilities, etc. are fully available.
- Assume a product mix that was **typical** or representative of your production during the fourth quarter. If your plant is subject to short-run variation assume the product mix of the current period.
- Do not assume increased use of productive facilities outside the plant for services (such as contracting out subassembly work) in excess of the proportion that would be normal during the fourth quarter.

Capacity Utilization

Your plant's capacity utilization rate should be based on a capacity output measure that your plant could have.

Assessing capacity in the United States Northwest Atlantic pelagic longline fishery for highly migratory species with undesirable outputs

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ABSTRACT

The Food and Agriculture Organization of the United Nations (FAO) and its member nations have embarked on an ambitious global plan to address excess capacity in fisheries. Under the International Plan of Action, its member nations have voluntarily agreed to assess and address excess harvesting capacity. To date, however, the assessment of capacity has ignored undesirable bycatch. In this paper, we present a method for estimating capacity, recognizing that reductions in undesirable outputs may also cause reductions in the capacity output. Our results indicate that the capacity output for sharks, tunas and swordfish would be reduced relative to observed outputs when reductions in the inadvertent capture of sea turtles would be required.

1. INTRODUCTION

Excess capacity has been recognized by the Food and Agriculture Organization of the United Nations (FAO) and its member nations as an issue of global concern. In addition, the FAO and its member nations have recognized the problem of incidental or inadvertent capture of unmarketable bycatch, most which is released or discarded at sea. There are several kinds of bycatch. First, there are species, such as sharks and other large fishes, sea turtles, seabirds and marine mammals, some of which are legally protected and others of which are perceived by the public as deserving of protection. Second, there are species that are not the object of tuna fisheries, but are the object of artisanal and recreational fisheries. Third there are juvenile tunas and billfishes that are so small that they are unmarketable. Fourth, there are species that are of little commercial value that are discarded at sea or landed and sold at low prices for the production of fish meal or pet food. To date, most assessments of capacity, have ignored the potential relationship between capacity output and bycatches. If bycatch reduction is an objective of capacity reduction programmes, failure to consider bycatches in the estimation and assessment of capacity will result in overestimating the capacity output. Alternatively, estimates of capacity output that exclude the potential for reducing undesirable outputs will be greater than estimates of capacity, which attempt to directly incorporate reductions in undesirable outputs.

In this paper, we expand the traditional data envelopment analysis (DEA) approach for estimating capacity to explicitly allow for the reduction or non-expansion of undesirable outputs. Instead of using the conventional output distance function approach described by Kirkley and Squires (1999) and Pascoe *et al.* (2003), we introduce the notion of a directional distance vector, which allows for the estimation of capacity relative to desirable outputs, while simultaneously allowing for reduction of undesirable outputs. We illustrate the methodology using set-level data obtained from gear experiments conducted by pelagic longline gear operations in the distant-water area off the northeastern United States . The results, although limited relative to depicting capacity representative of the entire fleet, indicate that capacity output, when estimated conditional on reducing undesirable outputs, is considerably less than estimates of capacity output that ignore reduction of the levels of undesirable outputs.

2. DEFINITIONS AND CONCEPTS

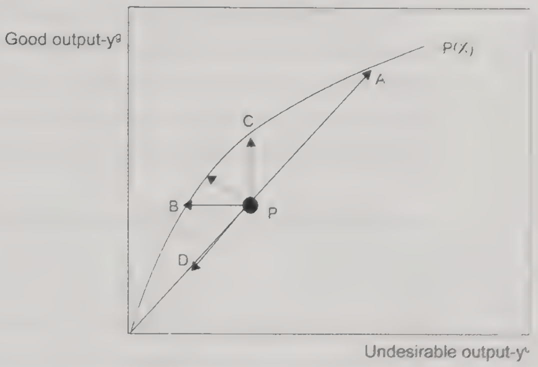
FAO has formally defined capacity as "the amount of fish (or fishing effort) that can be produced over a period of time (*e.g.* a year or a fishing season) by a vessel or a fleet if fully utilized and for a given resource condition". This concept of capacity is utilized in this paper. As such, it is a technological-economic measure of capacity output (Kirkley, Morrison Paul and Squires 2002).

In contrast to previous assessments of capacity, however, we recognize two types of outputs in this paper. First, we consider the conventional notion of desirable or marketable outputs (*i.e.* legal commercially-landed product). In addition, we consider undesirable products, which cannot be marketed for the reasons mentioned above or which can be marketed only at at prices much less than those of the object species. Because of the inclusion of undesirable outputs, we modify the basic definition of capacity output to specifically include the notion of reducing or preventing the capture of undesirable outputs. Alternatively, capacity output is the amount of fish that can be produced over a period of time by a vessel or a fleet, if fully utilized, given resource conditions, and adjusted to reflect the potential reductions in undesirable outputs.

We also introduce an alternative notion of the distance function—the directional distance function. In previous DEA-based assessments of capacity, an output distance function was estimated to determine the potential expansion in outputs, given the fixed factors (*e.g.* vessel size and engine horsepower) of production. In the present study, a directional distance function is estimated, which explicitly allows for the expansion of desirable or good outputs and contraction of undesirable or bad outputs, subject to the constraints of the fixed factors.

To gain a better understanding of the differences in using the output *vs.* directional distance function approach, consider Figure 1. A production possibilities frontier (*i.e.*, maximum output levels for a given level of inputs) is depicted as P(X). One good and one bad output are produced in the example. The production level of the good output is depicted on the vertical axis, and, that of the bad output on the horizontal axis. Note that in this example good outputs cannot be produced without some level of bad outputs; this is referred to as the null-joint property. Let point P be a point representing levels of good and bad outputs. With the conventional approach of using the output distance function to estimate capacity, we seek to determine the maximum expansion of both good and bad outputs subject to the limitations imposed by the fixed factors (*e.g.* point A in Figure 1).

FIGURE 1
Range in directions for expanding (contracting) outputs



With the directional vector approach, however, we can determine expansions (or contractions) in the levels of good outputs and contractions or no changes in the levels of bad output. In other words, solutions can be determined that are in the direction of B (increase in good output and decrease in bad output), C (increase in good output and no change in bad output) or D (decrease in both good and bad outputs).[1] In this paper, we seek primarily expansions of good outputs and contractions of bad outputs in the direction between B and C. For comparative purposes, however, we also estimate capacity output for the case of contracting good output along with bad output (*i.e.* direction D).

3. THE PELAGIC LONGLINE FISHERY, THE GOOD AND BAD OUTPUTS AND THE DATA

The pelagic longline fishery of the Northwest Atlantic is a multi-species fishery, and the type of gear employed or the configuration of the gear can be changed from trip to trip to secure the best economic opportunity for that trip. The fishery operates between Maine and Florida, but the majority of the catch is taken in the Mid-Atlantic region.[2] The fishery targets primarily swordfish and tunas, but also captures and lands various sharks. There are approximately 171 United States -flag vessels active in the entire Atlantic and Gulf of Mexico fisheries. The targeted or desirable outputs are swordfish (*Xiphias gladius*), albacore tuna (*Thunnus alalunga*), yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), bluefin tuna (*T. thynnus*) and sharks. The undesirable outputs are loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles. In the analysis the two species of turtles are linearly aggregated (*i.e.* the total number of turtles caught is equal to the sum of the numbers of the two species caught).

The estimation and assessment of capacity in this fishery utilized data obtained from numerous at-sea experiments conducted in 2002 and 2003 that were designed to assess the performance of different hook sizes and types (J hooks *vs.* circle hooks), different types of bait and the use of lightsticks (Watson *et al.* 2005). The experimental data were obtained from the Northeast Distant Water area, which includes waters east of 60°W between 35°N and 55°N (Scott and Diaz, this volume, Figure 4a). This area has been closed to commercial fishing for several years. Thirteen vessels, which made more than 1 900 sets, participated in the experiment, but the data for only 251 of these were usable, and the others did not meet the requirement that there be at least one good and at least one bad output for the set. The landings data are expressed as dressed weights and the sea turtle catches in numbers of animals caught. Information was available on the following inputs: (1) horsepower of engine, (2) length of vessel, (3) duration of soak, (4) duration of haul, (5) duration of set, (6) distance between gangions, (7) length of mainline, (8) number of hooks, (9) number of lightsticks, (10) number of floats and (11) number of radio beacons. For the purpose of estimating capacity output, engine horsepower and vessel length were considered to be the only limiting or fixed factors; all the other factors of production or inputs were considered to be variable inputs.

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[1] Lee, Park and Kim (2002) provide a comprehensive overview of selecting the direction of directional distance vectors in the estimation and analysis of technical efficiency.

[2] The majority of the catches of highly migratory species (HMS) are harvested by the pelagic longline fishery of the Gulf of Mexico.

4. METHODOLOGY, DATA ENVELOPMENT ANALYSIS AND DIRECTIONAL VECTORS

Although there is no officially sanctioned or internationally accepted method for estimating capacity output in fisheries, the most widely used approach, to date, has been data envelopment analysis or DEA (Pascoe *et al.* 2003; Kirkley, Morrison Paul and Squires 2004). Furthermore, only the output-oriented version of DEA, or an output-only directional vector approach, have been used to estimate capacity in fisheries.[3] Since the details of the conventional output-oriented approach have been widely published in various FAO publications (*e.g.* Kirkley and Squires 1999; Pascoe *et al.* 2003), we present only the details of the directional distance function approach. The directional distance vector approach is quite similar to the traditional output-oriented DEA approach. We seek to determine the maximum expansion, but only for the good outputs, while conditioning the expansion on the same proportional reduction in bad outputs (*e.g.* if it is determined that the capacity output of tuna is 25.0 percent more than the existing level of observed landings of tuna, then the level of bad outputs is reduced by 25.0 percent).

With the traditional output-oriented model, capacity is estimated according to the model formulation and restrictions of Färe (1984) and Färe, Grosskopf and Kokkelenberg (1989). This is a mathematical programming problem, which seeks to determine the maximum proportionate expansion in all outputs, given no change in the fixed factors of production, but allowing for changes in the variable factors (*e.g.* fuel and labour) of production. The proportionate expansion is estimated by solving for the inverse value of an output distance function, which is done for every observation included in the analysis.[4]

The directional vector approach also seeks to determine the maximal expansion in good outputs, but subject to contractions of the bad outputs. In this study, we impose the condition that the proportionate maximal expansion of good outputs is also equal to the proportional maximum contraction of bad outputs (*e.g.* a 25-percent increase in good outputs relative to observed levels is accompanied by a 25-percent decrease in bad outputs relative to their observed levels).[5]

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[3] The output orientation directional vector approach is the directional vector approach in which only outputs are allowed to increase, given that inputs are held constant, and reductions in bad outputs are not allowed. This approach yields the same estimates of capacity as does the more traditional output-oriented DEA approach.

[4] An output distance function is the mathematical distance between an observed output bundle (or output in a single output case) and the output bundle corresponding to the potential maximum or frontier output. The maximum potential output is a benchmark level of production determined by vessels of similar sizes. This is similar to the concept of efficiency ratings used to rank appliances of a particular type (*e.g.* water heaters). Initially, energy consumption is calculated for a group of appliances of similar sizes and price ranges; energy consumption of all except the most energy-efficient appliance are compared to the energy consumption of the most energy-efficient appliance, and a rating is assigned.

[5] This is not a requirement of the directional vector. It is possible to determine different levels of expansion for each good output and different levels of contraction for each bad output. This concept, which is described by Koopmans (1951) is referred to as the Pareto-Koopmans concept of efficiency

The following mathematical programming problem was specified and used to estimate capacity output such that good outputs and bad outputs are required to expand and contract, respectively, by the same proportion, β:

$$\overrightarrow{D_O}(x^{j'}, y^{j'}, u^{j'}; g) = \underset{\beta,z}{Max}\, \beta$$

$$s.t.$$

$$\sum_{j=1}^{J} z_j y_{jm} \geq y_{j'm} + \beta g_m, m=1,....., M$$

$$\sum_{j=1}^{J} z_j u_{jk} = u_{j'k} + \beta g_k, k=1,....., K$$

$$\sum_{j=1}^{J} z_j x_{jn} \leq x_{j'n}\, n=1,....., N$$

$$\sum_{j=1}^{J} z_j = 1.0,$$

$$z_j \geq 0, j = 1, ..., J.$$

where $\overrightarrow{D_O}$ is the directional vector; x is a vector of fixed factors (vessel length and engine horsepower); y is a vector of good outputs (weights of desirable outputs of swordfish, tunas, and sharks; u is a vector of bad outputs (number of sea turtles); the g functions are the directions of the distance vectors (1.0 for good outputs and –1.0 for bad outputs); there are J observations, M good outputs, K bad outputs, and N inputs or fixed factors; β is the value of the directional distance vector, and equals 0.0 if the observed good (bad) output cannot be increased (decreased), and is >0.0 if the observed good (bad) output can be expanded (contracted) (the level of expansion (contraction) equals the value of β); and the constraint $\Sigma z_j = 1.0$ imposes variable returns to scale.

The equality constraint

$$\sum_{j=1}^{J} z_j u_{jk} = u_{j'k} + \beta g_k, k=1,....., K$$

requires additional consideration. This constraint imposes what is referred to as weak subvector disposability. Weak subvector disposability, in constrast to strong subvector disposability, imposes the condition that it is not costless to catch and dispose of bad outputs; alternatively, in this formulation, it explicitly recognizes that labour must be reallocated to dispose of undesirable outputs, and reductions in bad outputs may cause reductions in good outputs. In the traditional framework for assessing capacity, strong disposability, or the conditional that there is no cost of disposing of undesirable outputs, is imposed on the technology. This is straightforward mathematical (linear) programming problem, and it is solved for each observation. The solution yields values of β, for which the percentage by which good and bad outputs, respectively, may be expanded and contracted.

5. RESULTS: ESTIMATES OF CAPACITY OUTPUT UNDER DIFFERENT ASSUMPTIONS

The previously discussed DEA model was estimated under the following basic assumptions: (1) both good and bad outputs could expand, and the cost of disposing of bad outputs is 0.0 (*i.e.* strong disposability is imposed); (2) good outputs could expand according to allowable capacity levels, while bad outputs must be reduced (subvector

TABLE 1
Summary statistics per set of pelagic longline experimental data

Statistic	Horsepower	Length	Swordfish	Albacore	Yellowfin	Bigeye	Bluefin	Shark	Turtles
Mean	465	20.7	433	8	2	44	10	257	1
N	251	251	251	251	251	251	251	251	251
Minimum	265	17.7	0	0	0	0	0	0	1
Maximum	850	25.9	2 003	123	186	509	222	1 201	18
Total			108 565	1 907	533	11 061	2 442	64 570	376

The weights for the desirable species are in kilograms, and the output of sea turtles is measured in numbers of turtles caught. N is the number of observations.

TABLE 2
Observed and estimated capacity output of desirable and undesirable outputs

Allowable expansion and contraction	Swordfish	Albacore	Yellowfin	Bigeye	Bluefin	Sharks	Turtles
Observed levels	108 565	1 907	533	11 061	2 442	64 570	376
Conventional approach: expand good and bad	256 193	2 836	631	21 224	3 292	144 507	1 012
Directional vector: expand good and contract bad	120 440	2 028	535	11 939	2 571	70 380	337
Directional vector: contract good and bad	94 152	1 625	399	9 577	1 928	53 810	255

The weights for the desirable species are in kilograms, and the output of sea turtles is measured in numbers of turtles caught.

weak disposability); and (3) both good and bad outputs must be reduced (global weak disposability). In the first case, the directional functions equal 1.0; in the second case, the directional distance of the good output equals 1.0, and the directional distance of the bad output equals -1.0; in the third case, the directional functions for the good and bad output both equal -1.0, thus forcing reductions in both the good and bad outputs. Estimation was accomplished using user-written code available in LINGO (2002).

Capacity was estimated using the 251 observations obtained from the experiments to assess options for reducing the bycatch of sea turtles in the pelagic longline fishery. Given the limited number of observations, the results should be viewed as representative only of the 13 vessels participating in the experiments, rather than of the entire pelagic longline fleet. The lengths of the vessels ranged from 17.7 to 25.9 m, and their engine horsepowers from 265 to 850 (Table 1). The average lengths and horsepowers for the entire pelagic longline fleet of the Northwest Atlantic and Gulf of Mexico pelagic fishery were 18.0 m and 441 horsepower. The landings of swordfish per set ranged from 0 to 2,003 kg, with an average of 433 kg, and the average landings per set of albacore, yellowfin, bigeye, bluefin and sharks were 8, 2, 44, 10 and 257 kg, respectively.

We next consider the potential expansions and contractions of desirable and undesirable outputs. The desirable outputs are swordfish, albacore, yellowfin, bigeye, bluefin and sharks, and the undesirable outputs are sea turtles. Based on the conventional approach for estimating capacity, we observe that the capacity output for swordfish, bigeye, and sharks is almost double or slightly more than double the observed levels of production; and capacity output is only slightly greater for albacore, yellowfin and bluefin (Table 2). There is, however, a 169-percent increase in the number of sea turtles captured. When good outputs are allowed to expand, but the undesirable outputs must be decreased or remain unchanged, capacity output is only slightly greater for all of the desirable outputs, and there is a decline in the number of sea turtles caught. If it is assumed that all products are complements (desirable and undesirable outputs must jointly increase or decrease) and the only way that the sea turtle catch can be reduced is to reduce the desirable outputs, capacity output is decreased to levels less than the observed levels. This last condition also yields the greatest reduction in the capture of sea turtles—from 376 to 255 turtles.

6. CONCLUSIONS

In this brief study, it was demonstrated that if managers desire estimates of capacity conditional on recognizing that the production of undesirable outputs should be reduced, the conventional DEA approach or the strict output-orientation produces greater estimates of capacity than do procedures designed to incorporate a reduction in undesirable outputs. The notion of a directional vector or directional distance function was introduced, and used to demonstrate a method for estimating capacity when there is a need to consider the reduction of undesirable outputs.

In this study, there were six desirable outputs and one undesirable one. The desirable outputs were swordfish, albacore, yellowfin, bigeye, bluefin and sharks, and the undesirable output was the number of sea turtles caught. Since only 251 observations for only 13 vessels were included in the data set, it is not possible to draw representative conclusions about the entire pelagic longline fleet, either in the Northwest Atlantic or the Gulf of Mexico.

This paper, thus, offers mostly an alternative methodology for estimating capacity, as opposed to an empirical study or examination of the capacity for an entire fleet. Fisheries management around the world, however, is increasingly emphasizing reductions in bycatches of protected and unmarketable species. The approach offered in this paper is one way to assess capacity while incorporating such concerns. In addition, as management agencies increasingly collect more data on discards, *etc.*, through logbooks, at-sea observers and other procedures, it will become increasingly easier to examine the relationship between capacity output and undesirable outputs.

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Factors affecting recent developments in tuna longline fishing capacity and possible options for management of longline capacity

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ABSTRACT

A study of the changes that have affected the fishing capacity of large longline vessels since the second Meeting of the Technical Advisory Committee of the FAO Project on the “Management of Fishing Capacity: Conservation and Socio-economics” in 2004 has been conducted. The numbers of large longliners, their total fishing capacity and their catches appear to be declining. This decline is due to scarcity of fish, scrapping of vessels to comply with government regulations and industry agreements and economic factors (increasing prices for fuel, decreasing prices for fish and competition with small longliners and with purse seiners). The recommendations made at the second meeting of the Technical Advisory Committee should be implemented for all the fleets. Particular concern is expressed regarding small longliners and purse seiners, for which the fishing capacities seem to have been increasing during recent years.

1. INTRODUCTION

At the second Meeting of the Technical Advisory Committee of the FAO Project on the “Management of Fishing Capacity: Conservation and Socio-economics” (held in Madrid on 15-18 March 2004) it was proposed that a Workshop be held to develop quantitative methods to determine the desired magnitude of or the desired change to fishing capacity on the basis of the status of stocks. This proposal was adopted, and the Workshop was held in La Jolla, California, USA, on 8-12 May 2006. The objectives of the Workshop were:

A. to develop quantitative methods to determine the desired magnitude of or desired change to fishing capacity on the basis of the status of stocks, taking into account the multi-species and multi-gear nature of tuna fisheries;
B. to determine the feasibility of (1) routinely collecting input data for Data Envelopment Analysis (DEA) and (2) performing industry surveys of tuna fishing capacity utilization;
C. to relate DEA estimates of fishing capacity utilization to traditional estimates of fishing capacity;
D. to review the factors affecting fishing capacity (numbers of vessels, their physical characteristics, *etc.*) that could be regulated by fisheries authorities;
E. to review the existing measures for managing tuna fishing capacity, and possibly, to identify additional options for such measures in the context of the outcome of addressing Objectives A to D;

F. to prepare a Statement of the participants in the Workshop;

G. to formulate recommendations of the Workshop to the FAO Project on the Management of Tuna Fishing Capacity, FAO and other organizations participating in the Workshop.

This paper is an update of a paper (Miyake, 2005a) submitted to the second FAO Technical Advisory Committee meeting on tuna fishing capacity. At that meeting it was concluded that the available longline data were not adequate for conducting DEA analyses. It was agreed, however, that the fishing capacity of the existing longliners more than 24 m in overall length (LOA) was more than adequate for catching the amounts of large tunas available at levels corresponding to their maximum sustainable yields (MSYs). Their economic breakeven point was actually higher than their average revenue, so the typical vessel was operating at a loss.

The trends in numbers of longline vessels, size compositions of the vessels, methods of operating, availability of fish and socio-economic elements that might have affected longline fishing capacity are reviewed in this paper.

2. DEFINITION OF LARGE LONGLINERS

At the second meeting of the Technical Advisory Committee it was recommended that "large longline" be applied to all longline vessels with the capability of freezing their catches. However, (Miyake, 2005a) had defined large longliners as vessels greater than 24 m in LOA that direct their effort at the principal market species, other than skipjack, of tunas (yellowfin, bigeye, albacore and the three species of bluefin) with freezing facilities (mostly super freezing) that sell their products for consumption as fresh fish *e.g.* sashimi or steaks. Swordfish longliners direct their effort at swordfish, usually using gear that fishes closer to the surface, and fish mostly at night.

It should be noted that most of the Regional Fisheries Management Organizations (RFMOs) have adopted "positive list" systems, which require registration of vessels more than 24 m in LOA, and some measures that adversely affect vessels that are not on the positive lists have been adopted, *e.g.* their catches cannot legally be traded internationally.

The previous report (Miyake, 2005a) concentrated on large longliners (those more than 24 m in LOA) because little information is available on small longliners. However, the numbers of small longliners and their catches have been increasing rapidly. Therefore, a section on small longline vessels is included in this report.

3. EFFORTS TO MANAGE THE TOTAL FISHING CAPACITY OF LARGE LONGLINE VESSELS BY GOVERNMENTS AND INDUSTRY, AND THEIR EFFECT ON THE FISHING CAPACITY OF THE WORLD FLEET

Information on efforts by various governments and by industry to control the numbers of large longline vessels is given by Miyake (2005a). The numbers of large longliners have been controlled by the limited-entry systems of most of the countries with major longline fleets for many years. In addition, following to the FAO International Plan of Action on fishing capacity, Japan and the Taiwan Province of China (TPC) have called back flag-of-convenience vessels (vessels owned by citizens of those countries, but registered in other countries) and scrapped many of them. The Organization for Promoting Responsible Tuna Fishing (OPRT) was established for this purpose.

The members of the OPRT register their large longline vessels with that organization every March; the numbers registered each year with the OPRT are shown in Table 1. The numbers in the shaded cells are estimates by the author of this report for the countries were not yet members of the OPRT. In 2005, almost all large tuna longline vessels were included in this list, the exceptions being a few (probably less than 30) vessels engaged in "illegal, unreported and unregulated" (IUU) fishing.

TABLE 1

Numbers of large longliners registered on positive lists of RFMOs

	2001	2002	2003	2004	2005
Japan	494	490	495	473	434
Taiwan Province of China	567	562	599	597	600
Republic of Korea	183	183	176	174	172
Philippines	6	6	17	17	18
Indonesia	-	-	14	14	14
China	98	100	105	105	113
Ecuador	-	-	-	5	5
Vanuatu-Seychelles	-	-	-	69	69
Total	1 348	1 341	1 406	1 454	1 425

The shaded cells indicate years in which the countries were not members of the OPRT (source: OPRT).

The total number of longliners included in the Table 1 increased from 2002 to 2004, but this does not mean that newly-built vessels entered the fishery. Rather, it indicates that many IUU vessels changed their registration to countries that were members of the OPRT, and therefore, were no longer IUU vessels.

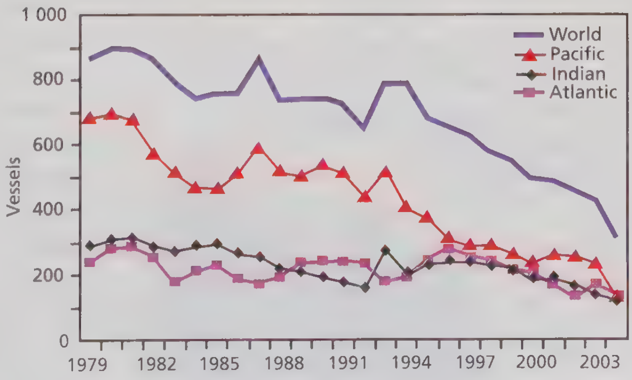
With the exception of vessels registered in European and Western Hemisphere countries, almost all countries in which large longliners are registered are members of the OPRT. It should be noted that most of the large longliners of European and Western Hemisphere countries direct their effort towards swordfish, though some tunas are taken as bycatches by these vessels. Therefore, the current number of vessels in the OPRT list corresponds approximately to number of large tuna longliners in existence. The only exception is the IUU fleet, which has been reduced significantly, probably to less than 30 vessels at present. Miyake (2005a) estimated that there were 1,615 large tuna longliners in 2003, including IUU vessels, so it can be safely concluded that the total number of large longliners has been declining during the last few years.

It should be borne in mind that not all the registered and licensed vessels are actually engaged in fishing. The numbers of Japanese longliners engaged in tuna fishing in each year, estimated from logbook records provided by the National Research Institute of Far Seas Fisheries (NRIFSF), Fisheries Research Agency of Japan are shown in Figure 1.The procedures of estimation are described by Miyake (2005a). The numbers of vessels that fished in each ocean were counted independently. However, some vessels fished in more than one ocean during the same year, so duplications were eliminated to obtain the world totals. The data for 2004 are not complete, because information for some of the vessels has not yet reached the NRIFSF.

It is clear from Figure 1 that the number of active Japanese longliners has been declining steadily since 1994. This tendency is not necessarily indicative of what has taken place in other longline fleets. Unfortunately, information on the numbers of active vessels could not be obtained for the fleets of any other countries. It can be seen that numbers of vessels registered in the TPC actually increased, which is due, as pointed out previously, to registration of called-back IUU vessels in the TPC. However, the TPC declared that it would scrap 56 longliners in 2005 and 104 more in 2006. The Korean longline fleet has also been slightly reduced.

FIGURE 1

Numbers of active Japanese longliners, by ocean



Double-counting was eliminated in calculating the world totals.

4. TUNA RESOURCES AVAILABLE FOR LARGE LONGLINERS

4.1 Large longliners vs. small longliners

Most tuna stocks are exploited by more than one fishing gear (*e.g.* longlines and purse seines), which compete with one another for fish, so it unrealistic to attempt to estimate the sustainable quantities of the various species that are available to the longline fishery.

Miyake (2005a) estimated that the 2001 catch of tunas by large longliners was roughly 390 thousand tonnes. A more detailed analysis was conducted for the present report. The longline catches of albacore, bigeye, yellowfin and the three species of bluefin in the three oceans were tabulated by species, oceans and countries in which they were registered. Using his knowledge of the fisheries, the author divided the data in each species-ocean-flag stratum into the catches of large longliners, small longliners and longliners that direct their effort towards swordfish. Those separated catches, summed for longline types for each ocean, form the basis for Figures 2, 3, 4 and 5. The data for 2005 are very incomplete.

FIGURE 2

Catches by large, small and swordfish longliners in the Pacific Ocean

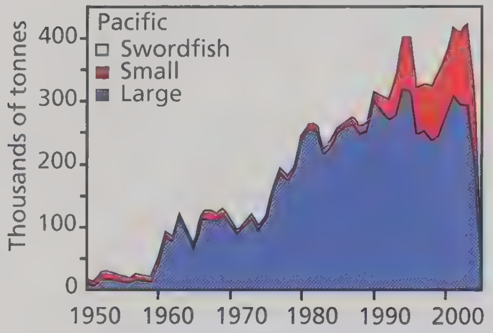


FIGURE 3

Catches by large, small and swordfish longliners in the Indian Ocean

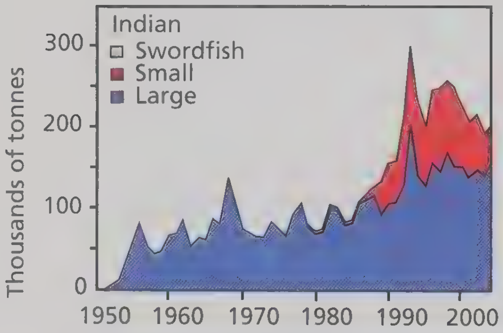
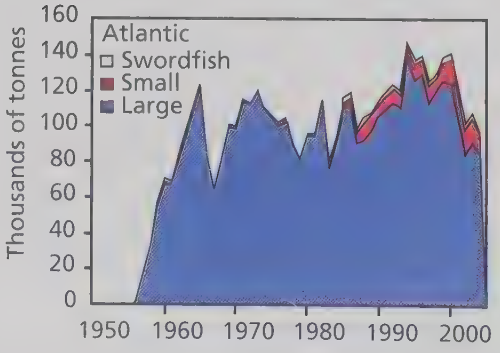


FIGURE 4

Catches by large, small and swordfish longliners in the Atlantic Ocean



It can be seen in Figure 5 that the longline catch increased sharply from about 100 thousand tonnes in 1959 to about 300 thousand tonnes in 1960, and thereafter gradually increased to about 500 thousand tonnes by the late 1980s. Another rapid increase, to about 800 thousand tonnes, took place during the early 1990s, but then the catches stabilized again. The catch by large longliners has been stable at about 500 thousand tonnes since 1990, and the increase during the 1990s is all attributable to increased catches by small longliners. This is particularly evident for the Indian and Pacific Oceans; the catches by small longliners in the Atlantic Ocean are still relatively small.

It should be borne in mind that the apparent increases in the catches by small longliners might be partly the result of improvements in the collection of statistics. The Indian Ocean Tuna Commission and the governments of some countries, *e.g.* Australia and Japan, have been aiding in the collection of data from coastal fisheries, particularly those involving small longliners. These improvements are mostly for the Indian Ocean and the western and central Pacific Ocean. However, it is not known how much of the increase is due to increased catches and how much to improved catch statistics.

In conclusion, from the mid 1980s to 2004, the catch of tunas by large longliners was stable at about 500 thousand tonnes. The catch by the small longliners increased from the mid-1980s to the mid-1990s. The catch of small longliners has been stable at about 200 thousand tonnes during recent years. These are probably close to the upper limits for the tunas (not including swordfish) available for longliners for the fresh fish or sashimi markets, under current conditions.

4.2 Competition among fishing gears other than longlines

4.2.1 Reduced catch rates

In general, the catch rates of the major species of tunas by longline vessels have been declining in many parts of the world due to excessive fishing effort, which has led to lesser abundance of the fish. The situation for bigeye tuna in the Atlantic Ocean, for which the catch rates declined from the late 1960s to the early 2000s (Figure 6) is typical. In this case, it was recognized that the stock has been fished down to a level close to or slightly less than that corresponding to the MSY.

4.2.2 Longline and purse-seine catches

In multi-gear fisheries, such as those for tunas, the reduction of a stock is often associated with activities of other gear, such as purse-seine gear, that can take large amounts of juvenile fish. The catches of tunas by purse seiners have increased rapidly since the early 1980s (Figure 7), and a large part of this increase has been due to increased used of fish-aggregating devices (FADs), which catch fish that are smaller, for the most part, than fish in free-swimming schools and fish that are associated with marine mammals. Purse seiners that fish on schools of fish associated with FADs catch mainly skipjack tuna, which are seldom caught on longline gear, but they also catch bigeye, the mainstay of the longline fishery, and yellowfin. When large amounts of juvenile fish of a species are caught, the overall yield per recruit and MSY of that species are reduced. The catches by longliners are reduced much more than those of purse seiners; in fact, those of purse seiners may not be reduced at all.

FIGURE 5

Catches by large, small and swordfish longliners in the world oceans

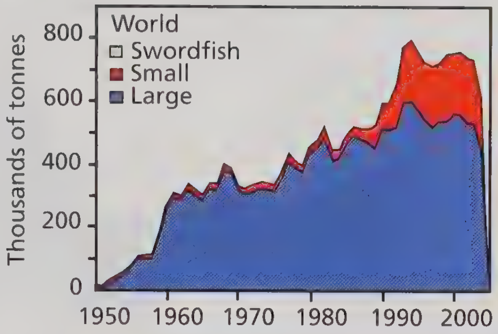


FIGURE 6

Standardized longline catch per unit of effort of bigeye tuna in the Atlantic Ocean (after SCRS, 2004; BET-Figures 4)

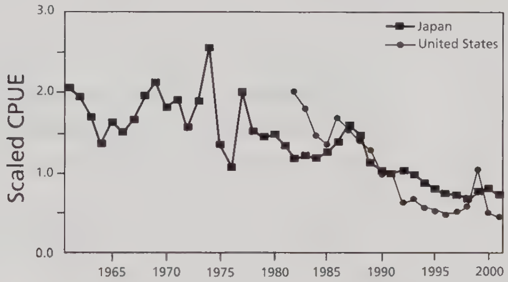
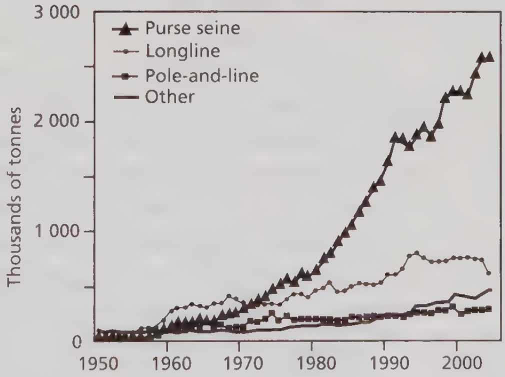


FIGURE 7

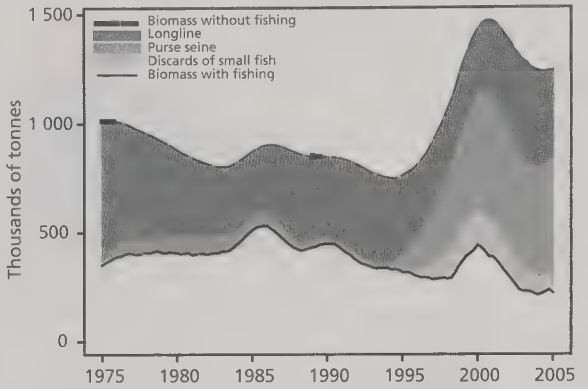
World catches of the principal market species of tunas, by gear



4.2.3 Effects of purse seine catches on the availability of fish to longline gear

The estimated effects (Maunder and Hoyle, 2006: Figure 4.12) of the purse-seine and longline fisheries on bigeye tuna in the EPO are shown in Figure 8. The small fish discarded at sea were all caught by purse seiners. It is clear that the increased catches of bigeye by purse seiners beginning during the early to mid-1990s were coincident with the decreased biomass of bigeye and the decreased catches of that species by longliners. Maunder and Hoyle (2006) attributed the decreases in biomass and longline catches to

FIGURE 8
Effects of catches of various gears on the biomass of bigeye tuna in the eastern Pacific Ocean (after Maunder and Hoyle, 2006: Figure 4.12)



the increased catches of bigeye, nearly all juveniles, by purse seiners.

4.2.4 Conclusion

In conclusion, the amounts of some species of tuna available for longliners have been reduced, and are possibly still decreasing, due to the increased catches of small individuals by purse seiners. It is obvious, therefore, that reduction in longline fishing capacity alone will not increase the abundance of large tunas. There must also be a reduction in the fishing capacities of other gears, particularly of purse seiners, that catch smaller tunas. Reduction of the purse-seine fishing capacity would increase the amounts of bigeye and yellowfin available to the longline fishery, and probably increase the yields per recruit for those species as well.

5. FACTORS OTHER THAN CAPACITY MANAGEMENT MEASURES BY GOVERNMENTS AND INDUSTRY AFFECTING LONGLINE FISHING CAPACITY

5.1 Technological improvements

The major technological improvements in longline fishing up to 2004 are discussed by Miyake (2005b). Since that report was written, there have been some changes in the gear used aboard large longliners and in the methods of fishing. Until very recently, the mainline was set and retrieved once each day, but now a few vessels operating in the Indian Ocean and the western Pacific Ocean are using a shorter mainline, but setting and retrieving it twice a day. The effect of the new type of operation on efficiency is not well investigated or documented, but if it proves to be more effective than setting and retrieving a longer mainline once a day it is likely that it will be adopted by many more vessels. If that is the case, the fishing capacity would increase while the fleet size remained the same.

Technological changes may be introduced to protect non-target species, rather that to increase the catches of target species. Specifically, there is evidence that the use of circle hooks, rather than J hooks, reduces the bycatches of sea turtles and the severity of the injuries inflicted on the sea turtles that are caught (Watson *et al.* 2005). Many experiments are being conducted to determine the relative efficiencies of J hooks and circle hooks to determine their relative efficiencies for fish of various species and sizes in various conditions, but it is too early to evaluate the effects of changing from J hooks to circle hooks on fishing capacity.

5.2 Economic factors

5.2.1 Operating costs

The cost of fuel is an important part of the costs of operating a longline vessel. The average prices paid for fuel by Japanese longline vessels whose owners are members of the Japan Tuna Federation are shown in Figure 9. Fuel is sold at higher or lower prices on the world market, but it is obvious that the price of fuel has about doubled since 1999.

The cost of labour is also an important part of the costs of operating a longline vessel. Vessels of some countries, such as Japan and the TPC, have hired crew members from coastal developing countries, which reduces labour costs, but may also reduce efficiency.

5.2.2 Market conditions

5.2.2.1 Market prices

The prices of most industrial products are determined by the cost of producing them. The prices of fish, however, are determined mostly by the balance of supply and demand. In particular, it is difficult for domestic fishery products in a developed country to compete with imported fishery products from developing countries, where the production costs are less. Furthermore, as longliners are less efficient than purse seiners, the former cannot compete with the latter unless they can produce a superior product for which they can get higher prices.

FIGURE 9
Prices for fuel for Japanese tuna longliners

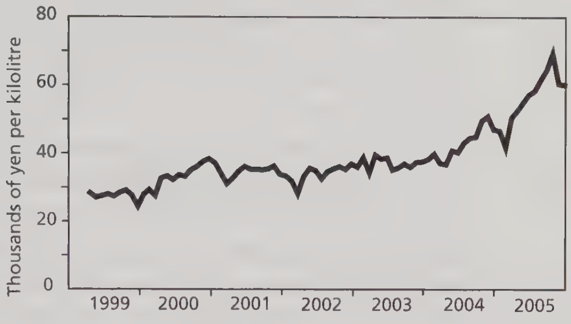
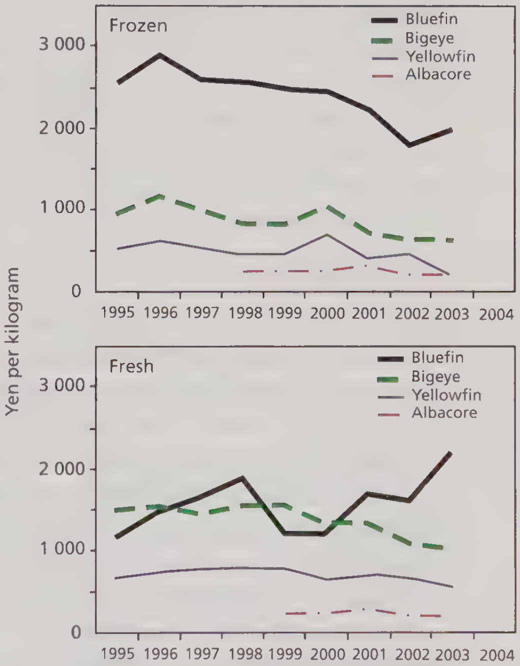


FIGURE 10
Average prices for domestic frozen and fresh tuna products in the Japonese market



The average prices of the major species of tuna produced by the Japanese tuna longline industry and consumed in the Japanese market are shown in Figure 10. (Data for the three species of bluefin are combined.) Data for imported products are not included in those used to produce this figure, but there is little difference in the prices of domestic and imported products of the same species, provided the quality is the same. The prices, with the exception of those for fresh bluefin, and possibly albacore, have been declining since 1996. The declines are possibly the result of a combination of over-supply of fish, competition from countries with lower producing costs, the condition of the Japanese economy and increased quantities of farm-raised tuna. The declines are more obvious for frozen tuna, which are products of large longliners. Comprehensive data were not available for years subsequent to 2003, but data for prices in the Tsukiji fish market show that the prices there were lower in 2004 and 2005 than in 2003, so it is almost certain that the downward trends continued after 2003.

Fresh tunas are obtained mostly from longliners that fish near the coasts of Japan. The prices for fresh bluefin are highly variable from year to year because the size composition of the fish is highly variable from year to year. Large bluefin are rarely caught near the coasts of Japan, and when even a few are caught the average price increases significantly. In contrast, the price of the frozen bluefin tuna, which competes with imported products (particularly with farm-raised bluefin tuna), has declined almost continuously.

5.2.2.2 Market structure

The structure of the market for tuna (for the world and within Japan) affects the fishing capacity, although it is difficult to quantify the magnitude of the effect. Air transportation of fresh fish to Japan used occur only sporadically, but now it is a well-established practice. The increased production of farm-raised bluefin in Australia, some Mediterranean countries and, most recently, Mexico provided an impetus for this, but tunas caught by small coastal longliners in southeastern Asia are also shipped by air to Japan. Fresh fish are transported to specific locations, and daily cargo flights carry them to their destinations. This establishment of routines has resulted in lower shipping costs.

Another notable development is the establishments of plants at ports of landing in coastal states where the fish are butchered. A few years ago the fish were sent to the Japanese central market as round or gilled-and-gutted fish. Wholesalers would buy entire fish at auctions at the central market, cut them into "blocks" and sell the blocks to retailers. The retailers would then prepare sashimi (from the blocks) at their own shops in accordance with customers' requests. Recently, however, some tuna have been cut into sashimi-size pieces and shipped to Japan and other countries where they are consumed. This practice significantly reduces the costs of preparing the fish and transporting them to their destinations.

5.3 Regulations

Regulations are either in effect or under consideration for most of the important tuna stocks of the world. There are several reasons for regulation, including regulations to protect stocks of tunas that are considered to be fully exploited or over-exploited, regulations to protect bycatch species, and regulations to prevent vessels not registered in a country from fishing within its EEZ. Among the types of regulations are catch limits, effort limits, area-time closures, gear restrictions, and measures restricting the ports at which fish can be landed. All of these can affect fishing capacity.

6. BYCATCHES

Virtually every fishery takes non-target species, including some that are in need of protection, such as some species of sharks, sea birds and sea-turtles. It has already been mentioned that if J-hooks are replaced with circle hooks the mortalities of sea turtles are likely to be reduced, but that such a change might affect the efficiency of the vessels. Closures in certain area-time strata can protect non-target species, but such closures are likely to reduce the efficiency of the longline vessels, as otherwise they wouldn't fish in those strata, and there would be no need for the closures. In addition, area-time closures can increase the costs of fishing, as the vessels would sometimes have to travel further to reach suitable fishing grounds.

7. SMALL LONGLINE VESSELS

There are apparently two different types of small longliners, multi-purpose longliners and longliners that target tunas. It is impossible to evaluate the fishing capacity of these small longliners, as not even information on the numbers of vessels is available. However, as discussed in Section 4, their catches have increased rapidly in recent years (Figures 2-5). A part of the increase could be a reflection of improved statistics, but most of it is the result of increased fishing capacity. Swordfish catches by the longliners targeting swordfish are not included in Figures 2-5. In addition, the numbers of swordfish longliners are increasing rapidly, except in the Atlantic Ocean, where a severe quota system has been adopted. However, the bycatches of tunas by swordfish longliners are minor.

7.1 Multi-purpose longliners

Multi-purpose longliners, *i.e.* boats that fish sometimes with longline gear and sometimes even other types of gear, such as harpoon, handline, trolling and/or gillnet gear, and target the species that will produce the greatest income at the time, are employed in many developed and developing coastal states. The potential fishing capacity is huge, but is related to the resources of tunas and other species available, their relative abundances and their relative prices. The management of multipurpose fleets would be very difficult.

7.2 Longliners that target tunas

In recent years there has been a marked increase in the numbers of small longliners that target tunas, and in the catches of tunas by these vessels. The most important reason for this increase appears to be the introduction of various fishing regulations, some of which apply only to the longliners more than 24 m in LOA.

Although these vessels are capable of traveling great distances, most of them cannot remain at sea for more than a few weeks, so they fish mostly in waters within the Exclusive Economic Zones (EEZs) of the countries in which they are based. However, they frequently change their flags to those of countries in whose waters they wish to fish or enter into joint-venture agreements with those countries. This behaviour makes it more difficult to collect information on these vessels.

Most of these vessels preserve their catches with ice, but some have freezing facilities, including super freezers. The most advanced small longliners are only slightly less than 24 m in LOA, and are equipped with super freezers capably of freezing as much as 20 tonnes of fish; the remainder of their catches are preserved with ice. The catches are sold mostly for marketing as sashimi- or steak-grade fish.

No comprehensive information on the numbers and the catches of small longliners is available, but because of their increasing importance, it is essential that such information be obtained.

7.3 Future prospects

If the current socio-economic conditions continue, it is likely that the number of large longline vessels will continue to decrease. However, the total longline fishing capacity is another matter because, as mentioned above, the number of small longline vessels has been increasing. If the demand for sashimi- and steak-grade tuna continues to increase the prices of fish are likely to increase, perhaps even to the levels of a few years ago. If so, unless restrictions on the entry of new vessels into the fishery are implemented, the overall fishing capacity is likely to increase. Because, as discussed earlier, small longliners are more efficient than large ones, the increase in fishing capacity would most likely be the result of entry of new small longliners into the fishery.

Unfortunately, management of the activities of small longliners would be difficult, as most of these vessels are registered in coastal developing states, and are exempt from current fishery management measures. In addition, the countries in which these vessels are registered may not be able to collect catch and effort statistics and control their activities, particularly since the owners of the vessels may not be citizens or residents of the countries in which the vessels are registered. Also, vessels may change their registrations from one country to another and/or shift their operations from one area to another. The problems that were encountered in handling large longliners engaged in IUU fishing have now shifted, to some extent, to small longliners. Since the numbers of vessels are even greater, and many more countries are involved, the scope of the problem is even greater than it was a few years ago. Therefore, management of longline fishing could be a major problem in the future.

8. A POSSIBLE SCHEME FOR MANAGING LONGLINE FISHING CAPACITY AND CONCLUSIONS

The recommendations made by the second meeting of the FAO Technical Advisory Committee are still valid.

In general, for various reasons, the fishing capacity of large longliners is declining. However, tuna fishing capacity as a whole is still increasing, while the tuna resources available to the longline fishery are not. In fact, due to increased catches of bigeye and yellowfin by the purse-seine fishery, the amounts of those species available to the longline fishery are less than they were during the years previous to the 1990s. It is clear, therefore, that if fishing capacity is not controlled the problems associated with overcapacity will become more serious in the future. The recommendations of the Technical Advisory Committee must be considered as the minimum requirements, and should be applied to all major gear types, and especially to purse seiners and small longliners, as the catches of those two types of gear are still increasing rapidly. Otherwise, the effort made to control the numbers of large longline vessels during the past several years would not achieve the intended result of reducing the overall effort to levels commensurate with the levels of abundance of the various species of tunas.

In the case of longliners, the problem lies with the small vessels. The first step to be taken would be to compile a list of small longliners, with information on registration, length, equipment for preserving the catches, *etc.*, which would not be easy. One way to accomplish this would be to lower the length limits for inclusion in the positive lists of the RFMOs. The cooperation of the developing coastal states in which these vessels are registered or in whose vessels these vessel operate would be essential to the success of any such measures.

A Statistical Document System (a system that requires that fish that are imported be accompanied by this document, validated by the government of the producing country, which includes information on the catch and the type and weight of the product) is currently in effect only for the Atlantic bluefin, Pacific bluefin, southern bluefin and frozen bigeye tuna (except that destined for canning), and for swordfish. Besides that, not all of the countries are implementing the system. If this system were applied to fresh bigeye, and also to yellowfin and albacore tuna, and if it were fully implemented, this would be helpful in assessments of the stocks of tunas affected by fishing by small longliners. However, that would require substantial expenditures and cooperation from all the countries that import tunas caught by small longliners.

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Tuna fishing capacity: perspective of the purse-seine fishing industry on factors affecting it and its management

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ABSTRACT

The tuna fisheries are multi-gear fisheries directed mostly at different life stages of skipjack, yellowfin, bigeye and albacore. Up to now, international management of tuna fisheries has been concentrated mainly on the outputs of tuna fisheries, *i.e.* catch, and much less on inputs *i.e.* effort and fishing capacity. Currently, assessments of tuna stocks are based largely on long series of catch and effort data, which are complete, or nearly so, for some fisheries, but not so for others, due to the extensive practice of Illegal, Unreported and Unregulated (IUU) fishing and the poor sampling coverage of some industrial fleets and many artisanal fleets. It is clear that that there must be limits on fishing capacity. Data for Spanish purse seiners that fish in the Indian Ocean indicate that the efficiencies of the individual vessels have been increasing, so this must be taken into consideration in selection of measures to control input.

1. INTRODUCTION

The status of most stocks of tunas is now highly uncertain because of different and complex elements, mainly political, that do not allow the members of the various regional fisheries organizations (RFOs) concerned with tunas to reach agreements that could lead to effective management.

The history of fisheries management tells us that no fishery under an open-access scheme has been able to maintain the resources at rational levels of exploitation (Gréboval, 1999; Gréboval and Munro, 1999; Cunningham and Gréboval, 2001). If the application of limited-access schemes has been difficult in local fisheries, which are normally controlled by a single country, one can imagine the difficulties that this has in tuna RFOs, with so many countries and so many interests involved.

Tuna fisheries, by the migratory nature of the species of fish involved, are, in principle, subject to open access to all participants—vessels of countries that are presently fishing and vessels of coastal countries with adjacency to the resource. Transition from an open-access fishery to a limited-access fishery has proven to be extremely difficult for tuna RFOs to implement, with only one scheme in operation (in the eastern Pacific Ocean), and this for only a segment of the fleet (the purse-seine fleet) (Resolution C-02-03 (Resolution on the Capacity of the Tuna Fleet Operating in the Eastern Pacific Ocean (Revised)) of the Inter-American Tropical Tuna Commission (IATTC).

The tuna fisheries are multi-gear fisheries directed at different life stages of skipjack, *Katsuwonus pelamis*, yellowfin, *Thunnus albacares*, bigeye, *T. obesus*, albacore, *T.*

alalunga and, to a lesser extent, three species of bluefin, *T. thynnus*, *T. orientalis* and *T. maccoyii*. Estimating an appropriate level of fishing capacity for even one fishery is a challenging problem. Up to now, international management of tuna fisheries has been concentrated mainly on the outputs of tuna fisheries, *i.e.* catch, and much less on inputs *i.e.* effort and fishing capacity. In contrast to other fisheries, indices of abundance are not obtainable from catch and effort data for purse-seine fisheries for tunas.

Currently, assessments of tuna stocks are based largely on long series of catch and effort data, which are complete, or nearly so, for some fisheries, but not so for others, due to the extensive practice of Illegal, Unreported and Unregulated (IUU) fishing and the poor sampling coverage of some industrial fleets and many artisanal fleets.

The levels of exploitation of the world tuna resources are reaching or have reached critical points for many stocks of fish, and management actions by most of the RFOs are urgently needed. Unfortunately, however, because of lack of information, this is difficult to do.

The World Tuna Purse-Seine Organization (WTPO), since its creation in 2001, has been calling for limitations on fleet capacity appropriate to the tuna stocks that they exploit to be applied by all the RFOs as the principal element for effective management.

2. THE FAO INTERNATIONAL PLAN OF ACTION FOR THE MANAGEMENT OF FISHING CAPACITY

The immediate objective of the FAO IPOA for the Management of Fishing Capacity (FAO, 1999) is “for States and RFOs, to achieve world-wide, preferably by 2003 but not later than 2005, an efficient, equitable and transparent management of fishing capacity. Inter alia, States and regional fisheries organizations confronted with an overcapacity problem, where capacity is undermining achievement of long-term sustainability outcomes, should endeavour initially to limit at present level and progressively reduce the fishing capacity applied to affected fisheries”.

It is clear that sometimes the good faith of governments in approving documents, such as the FAO IPOA for the Management of Fishing Capacity, for voluntary application within the FAO framework proves to be useless when some countries do not cooperate because the actions conflict with their political, social or economic interests. Of the five RFOs, only one, the IATTC, has been even partially successful in limiting fishing capacity, and that success was realized for only one segment of the fleet, purse seiners.

3. FACTORS AFFECTING FISHING CAPACITY

3.1 Effective fishing effort

The major problem affecting the estimates of tuna purse-seine capacity, is to correlate any measure used in capacity (*e.g.* cubic meters of storage space for the catch, gross tonnage (GT) or maximum tonnage of frozen fish that the vessel can carry) with fishing effort (days at sea, days fishing, *etc.*) and its reflection of effective fishing effort. Pella and Psaropulos (1975), Gascuel, Fonteneau and Foucher (1993), Fonteneau, Gaertner and Nordstrom (1999) and Soto, Morón and Pallerés (2000) have attempted to estimate the increases in fishing efficiency of purse-seine vessels with time, but, for the most part, their results have not been regularly taken into consideration in stock assessment.

The lack of the basic information with which to estimate the increases in fishing efficiency is a major problem that scientists encounter when addressing this problem. Tuna scientists have paid little attention to changes in fishing gear and techniques, which are key elements to consider in estimating the increases in fishing capacity of purse-seine vessels. Among the technical advances that have been identified as principal causes of increases in fishing efficiency are increased size of the vessels, the use of bird radar, sonar, echo sounders, fish-aggregating devices (FADs), radio buoys, satellite buoys, satellite information on sea-surface temperature, sea-level height, currents, ocean fronts, *etc*. (Increased size of the vessels contributes to efficiency because larger vessels are faster, and can search greater areas per unit of time than can smaller vessels.) Details as to when these elements were introduced to the tuna purse-seine fisheries and the extents to which they are used are unknown in most cases, and it would now be difficult or impossible to obtain this information.

Let us illustrate this with an example for the Spanish purse-seine fishery in the Indian Ocean. The Indian Ocean purse-seine fishery for skipjack and yellowfin could be considered a virgin fishery before the arrival of vessels from Spain and France in 1984. The stocks of skipjack and yellowfin could not be considered virgin stocks, however, because they were exploited by coastal fisheries, which targeted mainly skipjack, and longline fisheries, which took significant amounts of yellowfin, before the introduction of purse-seine fishing.

The trends in the catch rates for the Spanish fleet in the Indian Ocean, are quite similar for catch per vessel (Figure 1) and catch per days fishing (Figure 3), but very different for catch per GT (Figure 2). None of the three could be correlated with the estimated trends in abundance, which should be greater at the beginning of exploitation and less when the effort increases, as predicted by most biomass dynamic models (Hilborn and Walters, 1992: pages 76-89).

The average catch per vessel has increased by about 11 percent per year since the inception of the fishery in 1984. The increase in the catch per vessel during the first few years of activity (1984-1988) was probably due to familiarization of the fishermen with fishing conditions. After that, from about 1989 to 1993, the catches per vessel were approximately stable at about 5 500 tonnes. Then the catches per vessel increased again, averaging about 8 000 tonnes per vessel from 1999 to 2004). That increase in catch per vessel is the result of increased fishing efficiency, rather than to increased abundance of fish.

FIGURE 1

Catches per vessel by vessels of the Spanish purse-seine fleet in the Indian Ocean from 1984 to 2004, with the logarithmic trend

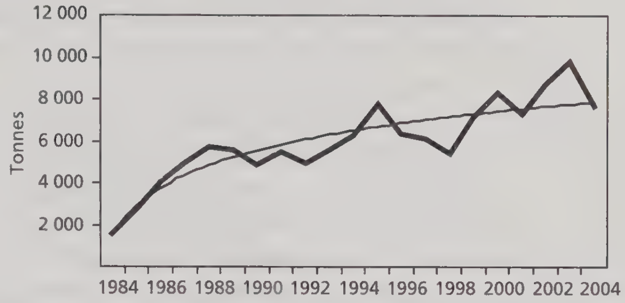


FIGURE 2

Catches per GT by vessels of the Spanish purse-seine fleet in the Indian Ocean from 1984 to 2004, with the logarithmic trend

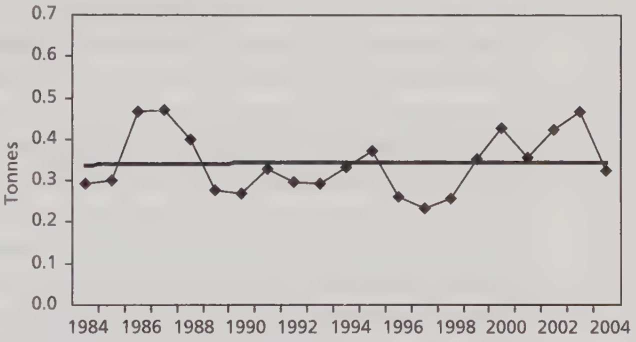
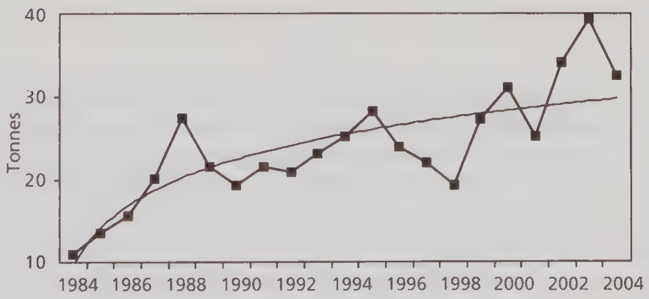


FIGURE 3

Catches per day of fishing by vessels of the Spanish purse-seine fleet in the Indian Ocean from 1984 to 2004, with the logarithmic trend



Despite the flat trend line in the catch rate as catch per total capacity in GT, the average increase during the entire period is about 3 percent per year, due mainly to the increase during the 1999-2004 period, when the average size of the vessels increased from about 800 GT to about 1 200 GT.

The general trend of the catch per days fishing indicates a yearly increase of about 4 percent for the entire period, but with four different periods:

- An increase during the early years (1984-1988), which is the logical situation in an underexploited fishery.
- A large decrease during 1989-1990, followed by a steady increase until 1995, probably due to the introduction of the use of FADs.
- A decline until 1998, corresponding to a large increase in fishing effort, averaging about 6 000 fishing days. (During the early years of the fishery the effort was never as great as 5 000 fishing days.)
- A period of great increase after 1999, which is probably related to technological changes that have increased the effective fishing effort, rather than to increased abundance of fish.

Various technical innovations have increased the effective fishing effort of the purse-seine fishery by increasing the ability of the fishermen to detect the presence of fish. In addition, other technical innovations have made it possible to set and retrieve the net and bring the catch aboard the vessel more quickly, which, in turn, increases the time available for searching for fish. Based on the research of Gascuel, Fonteneau and Foucher (1993) and Fonteneau, Gaertner and Nordstrom (1999), the Standing Committee for Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT), considered that there had been a 3 percent yearly increase of the effective fishing effort of the purse-seine fishery in the Atlantic Ocean. The Scientific Committee of the Indian Ocean Tuna Commission (IOTC) reached the same conclusion for the Indian Ocean, and this estimate coincided with the results of Morón (2004). This adjustment is useful, but it does not solve the basic problem of estimating the effective fishing effort in tuna purse-seine fisheries.

As we have shown, different catch rates can provide different estimates of the relative abundance of the fish. Therefore, a combination of effort and capacity estimates should be incorporated into any approach to estimation of optimal fishing capacity.

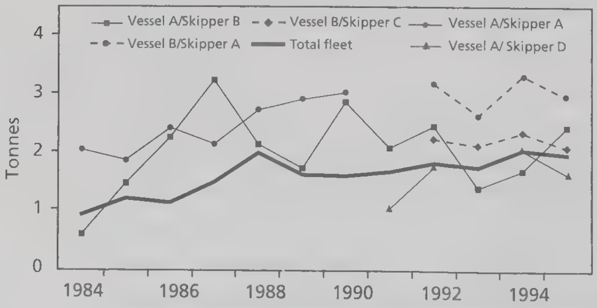
3.2 Skipper factor

The skill of the skipper (and the rest of the crew) of a vessel obviously affects its catches. (The skill of the rest of the crew can be ignored, as the most skillful skippers are able to attract the most skillful crews, so the effects of the two factors cannot be separated.) Few studies of the skill of the skippers of tuna purse-seine vessels have been made.

Some information on the catches per day of fish by four skippers aboard two vessels is presented in Figure 4. It can be seen that Skipper A was the most skillful, as his catches per hour of fishing exceeded those of the other skippers, except in 1987, whether he was aboard Vessel A or Vessel B. Skipper B, who was aboard Vessel A during every year of the 1984-1995 period, produced above-average catches during all but three of

FIGURE 4

Catch rates (tonnes per hour of fishing) of four skippers on two different vessels, compared with average catch rates of all skippers of the Spanish fleet operating in the Indian Ocean from 1984 to 1995 (redrawn from Morón, 2004)



those years. (Vessels often have different skippers on different trips made during the same year.) Skipper C, who was aboard Vessel B during 1992-1995, produced above-average catches in all four of those years. Skipper D, who was aboard Vessel A during 1991-1992 and 1994-1995 produced below-average catches in two of those four years.

Unfortunately, as was the case for technological improvements, extensive information on which skippers were aboard which vessels during which trips is not readily available, so it would be difficult or impossible to conduct detailed analyses of the effect of skippers on fishing success.

3.3 The multispecific nature of the purse-seine fisheries for tunas

The multispecific nature of the purse-seine fisheries for tunas complicates the management of tuna purse-seine fishing capacity. The purse-seine catches of tunas in the Indian Ocean include two principal species, skipjack and yellowfin. Bigeye are also caught, but the amounts are much less than those of skipjack and yellowfin.

The percentages of those three species in the purse-seine catches of tunas in four major ocean fishing areas are shown in Table 1. It is well known that the purse-seine catches in the western Pacific are dominated by skipjack (68 percent) and that those in the eastern Pacific are dominated by yellowfin (64 percent). The purse-seine catches of tunas in the Atlantic have a greater proportion of yellowfin (53 percent), whereas those of the Indian Ocean have a greater proportion of skipjack (50 percent). The percentages of bigeye in the purse-seine catches range from 3 to 7 percent.

The multispecific nature of the purse-seine fishery for tunas makes management of the three species difficult, as there is no level of fishing effort that is appropriate for all three species.

It is widely accepted that skipjack are not overfished in any the four major ocean fishing areas (IATTC, 2005; ICCAT, 2005; IOTC, 2005; SCTB, 2005), although in certain areas of the Atlantic there may be local depletion of skipjack (ICCAT, 2005).

TABLE 1

Average percentages of skipjack, yellowfin and bigeye in the purse-seine catches in the four major fishing areas (Sources: IOTC, ICCAT and Lawson, 2005)

Average proportion of each species	Skipjack	Yellowfin	Bigeye
Indian (1984-2004)	50%	44%	7%
Atlantic (1966-2004)	39%	53%	6%
Western Pacific (1951-2004)	68%	29%	3%
Eastern Pacific (1950-2004)	33%	64%	4%

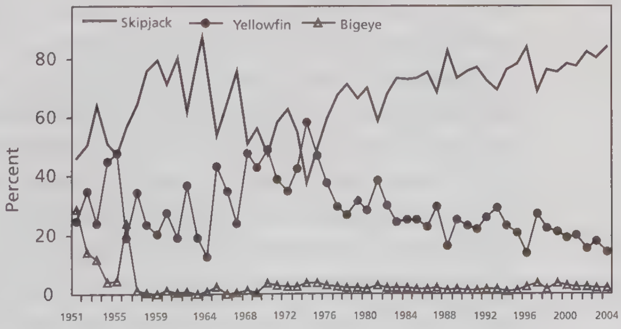
Yellowfin are exploited at about the MSY level in the eastern Pacific and the Atlantic (IATTC, 2005; ICCAT, 2005), but are somewhat above that level in the Indian Ocean and the western Pacific (IOTC, 2005; SCTB, 2005).

All of the bigeye stocks are considered to be overexploited (IATTC, 2005; ICCAT, 2005; IOTC, 2005; SCTB 2005).

When looking at the species compositions of the catches in the major fishing areas we observe different trends in the percentages of the various species in the catches.

FIGURE 5

Percentages of species in the purse-seine catches of the western and central Pacific Ocean from 1951 to 2004 (from Lawson, 2004)



The percentages of the three species in the purse-seine catches of the western and central Pacific Ocean are shown in Figure 5. The percentages that were yellowfin increased from the early 1960s to the mid-1970s, and then declined, making up only about 20 percent of the catch during the 1990s

FIGURE 6
Percentages of species in the purse-seine catches of the eastern Pacific Ocean from 1951 to 2004

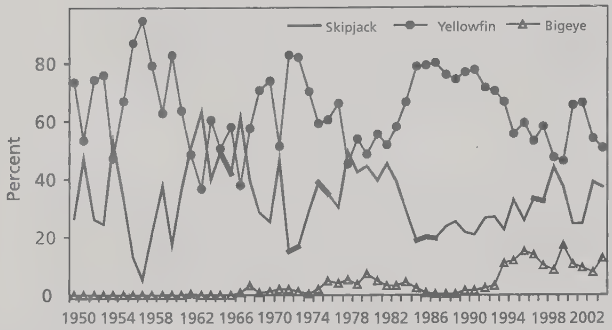
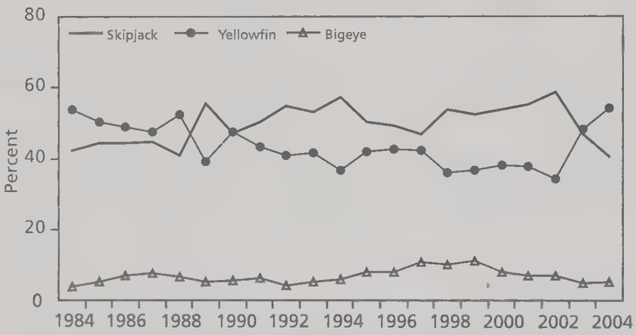


FIGURE 7
Percentages of species in the purse-seine catches of the Indian Ocean from 1984 to 2004



and early to mid-2000s. Skipjack, on the other hand, made up more than 50 percent of the catch in most years, and the percentages tended to increase after the mid-1970s. This increase could not be entirely due to the use of FADs, as FADs did not come into use until the early 1990s. The percentages of bigeye in the catches were relatively high during the early to mid-1950s, but then levelled off at less than 5 percent of the total catches.

The purse-seine catch of eastern Pacific Ocean has been dominated by the yellowfin since the early 1950s, except for a period during the 1960s when the skipjack and yellowfin catches were about equal (Figure 6). Since then the yellowfin catches have exceeded those of skipjack, except in 1978, and far exceeded those of skipjack from the mid-1980s to the mid-1990s. It should be noted that the percentage of the catch that was bigeye increased after 1993. It averaged 12 percent of the total during 1995-2004—greater than the percentage of bigeye in any other ocean fishing area. That increase in the estimated catches of bigeye was due mostly to the introduction of fishing on schools associated with FADs, but also to improved sampling of the catches, as bigeye had sometimes been recorded as yellowfin prior to the early 1990s.

The percentages of the catches of skipjack and yellowfin in the purse-seine fishery of the Indian Ocean are nearly equal, with the catches of yellowfin exceeding those of skipjack during 1984-1988 and 2004, and those of skipjack exceeding those of yellowfin during 1989, 1991 and 1993-2002 (Figure 7). About 10 percent of the catch was bigeye during the late 1990s, but it has been reduced to about 5 percent during recent years.

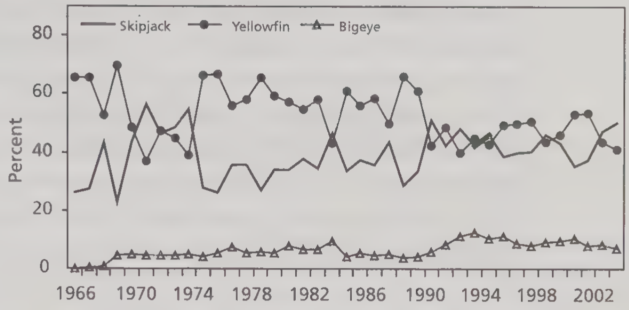
The percentages of the catches of yellowfin exceeded those of skipjack in the purse-seine fishery of the Atlantic Ocean from 1966 to 1990, except for 1971-1974 and 1984. Since 1991, the percentages of the catches of yellowfin and skipjack have been about equal (Figure 8). The percentages of bigeye increased during the early 1990s, averaging almost 10 percent from 1992 to 2004. This increase was probably due to the introduction of the use of FADs during the early 1990s.

Because, as noted above, the different species have been affected differently by the fisheries, we must consider the possibility of to applying different management options for the different species. In some cases, however, a species can be adversely affected by a fishery that is not directed at that species. For example, purse-seine fisheries are directed at skipjack and yellowfin, but their catches include minor amounts of bigeye. Most of the purse-seine catches of bigeye are taken in sets on FADs.

The decline in abundance of bigeye is the result of heavy fishing effort by longliners, catches of juvenile bigeye by purse seiners and unfavourable environmental conditions. Any management action taken should be directed at all fleets exploiting

FIGURE 8

Percentages of species in the purse-seine catches of the Atlantic Ocean from 1966 to 2004



the species under consideration, in this case both the longline and purse-seine fleets. The condition of bigeye led to studies of the interactions between the purse-seine and longline gear during the early 1990s (Shomura, Majkowski and Langi, 1994), without clear conclusions on the effects of the different gear types on one another.

Limitation of fishing capacity, a specific management action, should be applied immediately to the industrial fleets (mainly longline and purse seine) that exploit the two major tropical tuna stocks, bigeye and yellowfin, which are fully exploited or overexploited. This would prevent the situation from worsening. Once limitation of fishing capacity is in effect, other management measures could be implemented to regulate the exploitation of each species at its optimum level, whatever the reference point utilized.

4. EXISTING MEASURES FOR MANAGING TUNA FISHING CAPACITY

As we mentioned previously, the first actual management measure taken to control purse-seine capacity in a major fishing area was Resolution C-02-03 of the IATTC, "Resolution on the Capacity of the Tuna Fleet Operating in the Eastern Pacific Ocean (Revised)". Before that, the Palau Arrangement (FFA, 1992), was the first management instrument implemented at a subregional level to control a purse-seine fishery, setting a limited number of vessels to be licensed by the signatory countries of the Palau Arrangement. These are the only effective examples of fleet management in tropical tuna fisheries. Both are directed only at purse-seine fisheries. The numbers of purse-seine vessels, the importance of their catches and the fact that their catches are unloaded at relatively few major locations, which facilitates monitoring and control and minimizes IUU fishing, has made this fleet the first target for management..

4.1 The IATTC

Resolutions to limit the capacity of the tuna purse-seine fleet in the eastern Pacific Ocean (EPO) were approved by the IATTC at its 62nd meeting in October 1998 and by correspondence on 19 August 2000. After four years of intense negotiations and six meetings of the Special Working Group on Fishing Capacity, the 69th meeting of the IATTC adopted Resolution C-02-03.

Resolution C-02-03 provides every participant ("Parties to the IATTC, and States and regional economic integration organizations ..., and fishing entities that have applied for membership of the Commission or that cooperate with the management and conservation measures adopted by the Commission.) in the fishery a maximum fish-carrying capacity for its purse-seine fleet, with a not-well-defined provision for capacity transfer among participants. One of the major problems in the application of this resolution has been transfer of vessels among participants, which was not resolved until June 2005, at the 73rd meeting of the IATTC.

Resolution C-02-03 resulted in allocation of a maximum carrying capacity for each country, which was first measured in tonnes of carrying capacity, and later transformed into cubic metres of well volume, a more objective measure of carrying capacity. The countries whose fleets had less carrying capacity than the amounts that were allocated to them were given time periods in which to increase their capacities to the maxima that they were permitted to have. The principal goal of the negotiations was to freeze the overall fleet capacity at the level of 1998, although some changes were introduced between the time the negotiations began and the adoption of the resolution in 2002.

The issue of transfer of vessels among participants has been a problem. Some countries allow free entry and exit of vessels, recognizing rights of vessel owners to transfer their registrations from one country to another, but there are others that consider the fleet capacity to be a non-transferable right that belongs to the country. In the latter case, if a vessel owner transfers the registration of his vessel to another country, the government of the first country considers that it retains the same capacity allocation, and that it can issue the allocation of the transferred vessel to another vessel. The net result, unfortunately, has been that the total carrying capacity of purse seiners in the EPO increased from about 162 thousand tonnes in 1998 to about 206 thousand tonnes in 2004 (IATTC, 2005: Table A-11).

4.2 The Palau Arrangement

Concerns about the level of exploitation of tuna resources in the western and central Pacific Ocean (Muller and Wright, 1990), was the driving force to prepare the ground for the signatories of the Palau Arrangement. This arrangement first set a maximum number of purse-seine vessels to be licensed by the members of the Parties to the Nauru Agreement (PNA; Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu) in 1990, giving access to 164 purse-seine vessels in the EEZs of the PNA members, including the adjacent high seas of the WCPO in which purse-seine vessels operate. This concept is based on the legal framework of the United Nations Convention on the Law of the Sea, and for that reason it has received major support from countries that have large vessels that fish in the WCPO. The limit was later raised from 164 to 205 purse-seine vessels in 1993 (Dunn, Rodwell and Joseph, 2006).

This limit will remain effective until the new Vessel Day Scheme (VDS) enters into force in 2007. The reason for the change is to "enhance sustainability of the Western and Central Pacific purse seine fishery by controlling the level of fishing effort" from the biological perspective. From the economic perspective "it aims to increase economic benefits to resource-owning states by creating a real limit on fishing days that will create a demand from vessel operators for these days" (Dunn, Rodwell and Joseph, 2006).

The first concern of the vessel operators is the way that the number of days may be set. The general intention is to limit fishing effort to the 2004 levels, but there might be other elements taken in account when finalizing the total allowable effort, with particular focus on fishery development. There are other exemptions that will be considered in the new scheme to the Multilateral Treaty on Fisheries with the United States (UST) (FFA, 1987) and the FSM Arrangement for Regional Fisheries Access (FSMA) (FFA, 1994) that will reduce the number of days available for the rest of the operators.

The different fees to be paid in accordance with vessel size and the possibility of carrying over fishing days to future years, borrow fishing days from future years and transfer fishing days among PNA members could be, in a way, limited by the three-year limit of the scheme. This might result in situations in which no fishing days were transferred in one year, and an excess of fishing days were offered in the following year, producing excessive fishing effort in the latter year.

5. CONCLUSION

Hilborn and Walters (1992) mention a first principle on fisheries management: "You cannot determine the potential yield from a fish stock without overexploiting it". We believe that that time has not arrived for skipjack, but the other two species caught by the purse-seine gear, yellowfin and bigeye, are fully exploited or overexploited.

Unfortunately, the fishing effort for those two species is greater than that corresponding to the MSY levels, and scientists who have studied them recommend that the effort for the major gears that exploit them be limited or reduced.

Hilborn and Walters (1992) propose a second principle that is of key importance for the purpose of the management of tuna fishing capacity: "The hardest thing to do in fisheries management is reduce fishing pressure". In applying limitations on current fishing capacity in the four major tuna fishing areas, we will not address the problem of effort reduction. With a capacity limitation we only reduce the speed at which the problem worsens, because the effective fishing effort will continue to increase due to technological advances and other factors, and therefore the stocks will still be subjected to increasing fishing pressure.

A management scheme for the tropical tuna fleets should take into consideration the following principles:

- Recognizing the difficulties in assessing the fishing capacities that are appropriate to each stock status, applying the Precautionary Approach and the application of an immediate fleet capacity limitation to the current number of vessels operating in the four areas studied by for RFOs (IATTC, ICCAT, IOTC and WCPFC) should be the first priority.
- Any fleet capacity scheme should be applied equally to all the industrial fleets exploiting the two major tropical tuna species, yellowfin and bigeye, that are currently fully exploited or overexploited.
- Until a practical quantitative tool can be developed and adequate data that can be used with that tool to estimate fleet capacity relative to stock status, the total fish-carrying capacity of the current vessels, (preferably in cubic metres), should be used as the limiting factor for capacity.
- Under a RFO state-based capacity scheme, privately-generated rights should be considered by governments to allow free transfer of vessels among members of the RFOs in order to avoid later increases of capacity, which should provide legal security for vessel operators operating in different countries.
- Only vessels flying the flag of members or cooperating parties (CPCs) of the RFOs that are currently fishing in the areas studied by the RFOs and listed in the registers of those RFOs should be allowed to fish in those areas.
- Only vessels listed in the registers of the RFOs should be allowed to unload, transfer, store or market fish caught in the waters of the RFOs. Furthermore, the countries should not permit exportation or importation of fish that were caught by vessels that were not listed in the vessel registers of the RFOs responsible for the areas in which the fish were caught. Vessels that fish in areas for which they are not listed in the vessel registers will be considered to be engaged in IUU fishing.
- In order to link responsible fishing with responsible marketing, a marketing certificate should be issued to each vessel included in the RFO register, and only fish caught by vessels with certificates can be bought and sold.

Burrows (2006) mentions that "Perceptions of stakeholders must be addressed equally as well as facts in the allocation process if decisions are to be supported". This is a final remark that we want to address, because the lack of communication among stakeholders (mainly operators of small vessels registered in developing coastal countries and operators of larger vessels registered in distant countries) sometimes leads to intervention by third parties (government agencies, consultants, non-governmental organizations, *etc.*) with different interests or agendas. Any proposed management scheme should include involvement and support of the major stakeholders affected by the application of schemes to maximize the levels of compliance.

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Productivity growth in natural resource industries and the environment: an application to the Korean tuna purse-seine fleet in the Pacific Ocean

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ABSTRACT

Measures of multifactor productivity growth in natural resource industries are biased unless the effects on the environment are taken into account. This paper introduces environmental effects into an output-oriented Malmquist index of multifactor productivity growth to evaluate growth in productivity, technology and technical efficiency for Korean purse-seine vessels that fish for tunas in the western and central Pacific Ocean.

1. INTRODUCTION

An important issue for accurate measurement of multifactor productivity (MFP) growth in many industries is accounting for changes in the state of the environment. Environmental effects are particularly important for industries for and natural resources, such as agriculture, mining, forestry, fisheries and power generation, that are directly affected by the environment. Environmental changes can include short-term events, such as precipitation, temperature and El Niño-Southern Oscillation episodes, medium-term (decadal-scale events), and long-term climate change. These changes in the state of the environment are unpriced, so they require treatment in MFP measures that are different from that for priced inputs and outputs.

Some attention has been devoted to environmental effects on productivity and economic growth in the environmental, resource and productivity literature, but formal treatments in models of productivity growth and technical change have either overlooked environmental effects, or these ideas have not been fully developed. Bleischwitz (2001) provided a broad historical overview of the general subject of natural resources, the environment and productivity growth. Grubler, Nakicenovic and Nordhaus (2002) considered productivity growth, technical change and the environment in general. Jaffee, Newell and Stavins (2002) discussed environmental policy and technical change, although a formal treatment of productivity growth, including the impact of environmental factors, was not fully developed. The chapters in Simpson (1999) can be extended to explicitly include natural resource stocks and environmental factors. Squires and Reid (2001, 2002, 2003, 2004) estimated Malmquist indices of MFP growth for vessels of the different distant-water and coastal flag states in the tuna purse-seine fishery of the western and central Pacific Ocean (WCPO), accounting for changes in natural resource stocks and the state of the environment, but did not develop a formal treatment. Felthoven and Paul (2004) briefly surveyed environmental variables in MFP measures for fisheries. Arrow *et al.* (in press) broadly discussed the environment and natural resource stocks in productivity growth, and adjusted the Solow (1957) productivity residual for changes in natural resource stocks. In population dynamics literature, Freon (1988) allowed environmental variation in the environmental carrying capacity and catchability coefficient of surplus production models, both of which are otherwise constants.

Measures of multifactor productivity growth in natural resource industries are biased unless the effects on the environment are taken into account. Disentangling productivity growth from changes in natural resource stocks was addressed by Lasserre and Ouellette (1988, 1991) for non-renewable resources and Squires (1988, 1992) for renewable resources. Murray (2004) developed a theoretical model of technical change in natural resource industries. McConnell and Strand (1989) indicated that the change in biomass over time is positively related to the predetermined vectors of variables representing water quality, implying that improvements in water quality should increase the growth in biomass.

The process of productivity growth and technical progress in industries exploiting common resources, such as marine fisheries, can differ from that in some other natural resource industries for which productivity growth and technical progress are viewed as enhancing the resource stock. For example, in the above-mentioned common resources such as fisheries, productivity growth and technical progress simply increase the rate of exploitation. Also, the costs of producing forest resources today are no longer limited to the costs of extraction; the costs of planting, growing and harvesting are now a significant part of the total cost of producing these resources (Sedjo 1999). In this regard, economic and productivity growth in the forest sector are edging closer to agriculture and moving away from an industry that exploits natural resources as they are found in nature, *i.e.* as forestry moves from exploiting resources at the extensive margin to the intensive margin.

This paper formally and empirically incorporates unpriced environmental effects into measures of MFP growth by introducing sea-surface temperature (SST) into the stock-flow production technology for a renewable common resource, marine fish.[1] Specifically, this paper develops output-oriented Malmquist indices of multifactor productivity, technical change and technical efficiency, while accounting for changes in abundance of the fish stocks and the state of the environment, such as the SSTs. We specify the state of the unpriced environment as a technological constraint beyond the control of the individual firm, in a similar vein to the natural resource stock (Squires 1992), so that, following Gordon (1954) and McFadden (1978), it becomes a technology shift variable.[2] We evaluate productivity in a framework developed from the neoclassical theory of the firm for which there is a stock-flow production technology with a common natural resource.[3] The paper demonstrates that the output-oriented Malmquist index approach, which does not necessarily require cost, revenue or price data, is especially well suited to incorporate unpriced measures of fish stocks and states of the environment, such as climate and ecosystem services (*e.g.* nutrient flows and availability).

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[1] Empirical studies of natural resource industries to evaluate productivity growth and technical change in natural resource industries accounting for the resource stock include Squires (1992), Jin *et al.* (2002) and Hannesson (2006), who used Tornqvist index numbers, and Lasserre and Ouellette (1988), Campbell and Hand (1998) and Squires and Grafton (2000), who all used econometric techniques. Kirkley *et al.* (2004) examined embodied technical change, although without explicitly accounting for the resource stock. Simpson (1999), like many others who studied productivity and technical progress in natural resource industries, focused on extracted resources that serve as intermediate outputs, rather than on the actual resource exploitation phase. Fox *et al.* (2002) included resource stocks in a decomposition of profits.

We evaluate productivity growth for a micro-level panel (combined cross-section and time-series data) of Korean purse-seine vessels that fish for tropical tunas (essentially at the plant level) harvesting common-pool skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tunas in the Exclusive Economic Zones of the member countries of the Forum Fisheries Agency (FFA), using vessel-level data for 1997-2002. In general, there were precipitous changes during 1997-2002 in the entire tuna industry, due to the introduction of a major process innovation, fishing on drifting fish-aggregating devices (FADs) in 1997, coupled with a decline in fishing on free-swimming schools of tuna and on tunas that aggregate under flotsam.[4] However, the focus of the Korean fleet has remained largely on free-swimming schools of tuna and, to a lesser extent, on tunas aggregating under flotsam. Only a small proportion of the total fishing effort on tunas associated with FADs is exerted by the Korean fleet. The question arises as to whether the introduction of FADs has had a substantive effect on the MFP growth of the Korean fleet.

The paper finds that, due to the limited adoption of this process innovation (FADs) into the Korean fleet, MFP growth has been modest. It also demonstrates that failure to account for the natural resource stocks or the state of the environment leads to biased measures of MFP growth.

2. THE MALMQUIST PRODUCTIVITY INDEX

The multiproduct firm's stock-flow production technology represented by output distance functions is defined as: $D_t(y_t,x_t,B_t,z_t) = \inf\{\lambda>0(y_t/\lambda,x_t,B_t),S_t\}$. The distance represents the smallest factor λ by which to deflate output so as to be feasible or producible with given x_t, B_t and z_t under period-t technology. When there is a single good produced, $D_t(y_t,x_t,B_t,z_t) = y_t / f(x_t,B_t)$. $D_t(y_t,x_t,B_t,z_t)$ is non-decreasing, homogeneous of degree-one in output, convex in y_t, non-decreasing in x_t and jointly continuous in (y_t,x_t,B_t,z_t), and it is the reciprocal of Farrell's radial measure of output-oriented technical efficiency (Färe and Primont 1995).[5] The output distance function $D_{t+1}(y_t,x_t,B_t,z_t)$ relates observed output in time t to the maximum attainable with period t+1 technology.

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[2] Individual firms under open access, in most instances, have a negligible impact upon common resource stocks. Location decisions by individual firms can affect local densities and availability of common resource stocks, particularly for demersal (bottom-dwelling) species or for threatened and endangered species, but not for highly-migratory species, such as the pelagic oceanic tunas. Collectively, firms do impact the resource stock. Nonetheless, within the traditional static MFP framework based on the theory of the firm, the resource stock can be largely viewed as non-discretionary, rather than as an input under the control of the individual firm. The state of the environment is a technological constraint, and hence non-discretionary, and not an input *per se* under the control of an individual firm.

[3] For renewable resources, the approach is fundamentally static, since it implicitly assumes that management decisions and exploitation by individual firms do not measurably affect the resource stock over a short period of time. Thus, the approach is developed within the standard productivity literature framework, and is not explicitly dynamic.

[4] Fish-aggregating devices (FADs) reduce searching time for fish, since the fish naturally aggregate around the FADs, and the FADs may have radio beacons attached, which the vessels use to find the FADs. There have also been advances in the application of sonar and satellite technology (Itano 2003), which has contributed to MFP growth. The reduced searching time lessens variable inputs or reduces fishing effort expended for any quantity of fish caught, or increases the catch for any level of variable input usage, thereby contributing to productivity growth. Also, the success rates for sets on floating objects, such as FADs and flotsam, are greater than those for sets on free-swimming schools of tunas, which have a higher incidence of zero-catch sets. In summary, more fish are caught with FADs for given variable input usage; less time is spent searching for fish, and the average catches per set are greater.

The Malmquist MFP index, introduced by Caves, Christensen and Diewert (1982), uses distance functions, and builds upon the work of Malmquist (1953). The Malmquist output-oriented productivity for period-t technology can be written:

$$M = \frac{D_t(y_{t+1},x_{t+1},B_{t+1},z_{t+1})}{D_t(y_t,x_t,B_t,z_t)} \quad . \tag{1}$$

M measures the MFP change between two data points by calculating the ratio of the distances of each data point relative to a common technology. If period t+1 has a higher level of productivity than is implied by the period-t technology, then $M>1$.[6] Since two benchmark technologies for periods t and t+1 are not necessarily non-neutrally related or non-nested, the geometric mean is calculated (Caves, Christensen and Diewert 1982):

$$M = \left[\frac{D_t(y_{t+1},x_{t+1},B_{t+1},z_{t+1})}{D_t(y_t,x_t,B_t,z_t)} \frac{D_{t+1}(y_{t+1},x_{t+1},B_{t+1},z_{t+1})}{D_{t+1}(y_t,x_t,B_t,z_t)} \right]^{1/2} \tag{2}$$

The right side of Equation (2) can be decomposed into the product of technical efficiency change and technical change (Nishimizu and Page 1982, Färe *et al.* 1994):

$$M = \frac{D_{t+1}(y_{t+1},x_{t+1},B_{t+1},z_{t+1})}{D_t(y_t,x_t,B_t,z_t)} \left[\frac{D_t(y_{t+1},x_{t+1},B_{t+1},z_{t+1})}{D_{t+1}(y_{t+1},x_{t+1},B_{t+1},z_{t+1})} \frac{D_t(y_t,x_t,B_t,z_t)}{D_{t+1}(y_t,x_t,B_t,z_t)} \right]^{1/2} \tag{3}$$

The ratio outside of the brackets in Equation (3) measures the change in relative technical efficiency–the change in the distance of observed production from best-practice production–between periods t and t+1. The term within the brackets is an index of technical change from period t to t+1, and shows whether the best-practice frontier relative to the firm in question is improving, stagnant or deteriorating.[7] When any component is larger (smaller) than unity, there is improvement (deterioration).

The best-practice firms establish the production frontier, and the Farrell technical efficiency of all other firms is measured relative to this frontier. The time series of data then allows for estimation of technical progress (movement of the frontier established by the best-practice firms) and changes in technical efficiency over time (distance of the inefficient firms from the best-practice frontier)–"catching up" (Nishimizu and Page 1982, Färe *et al.* 1994).

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[5] Homogeneity of degree one in outputs implies $D_t(\lambda y_t,x_t,B_t,z_t) = \lambda D_t(y_t,x_t,B_t,z_t)$ for any $\lambda > 0$.

[6] Suppose the data point in period t+1 lay beyond the production possibility frontier or feasible production set defined by the period-t technology; then $D_t(y_{t+1},x_{t+1},B_{t+1},z_{t+1}) > 1$ ($i.e. \lambda > 1$) to deflate this data point to the frontier. Similarly, suppose the data point in period t lay below the frontier or feasible production set defined by the period-t technology; then $D_t(y_t,x_t,B_t,z_t) < 1$ ($i.e. \lambda < 1$) to inflate this data point to the frontier. Then $M = D_t(y_{t+1},x_{t+1},B_{t+1},z_{t+1}) / D_t(y_t,x_t,B_t,z_t) > 1$

[7] The technical efficiency change indicates whether the observation has gotten closer or farther from the frontier over time. The first ratio inside the bracket captures technical change and evaluates the shift in the frontier at the data observed in period t+1, whereas the second term captures that shift evaluated at the data observed in period t. Also, as observed by Färe, Grosskopf and Roos (1995), the period t and t+1 indices are equivalent only if the technology is Hicks output-neutral, so that the output distance functions may be written as $D_t(y_t,x_t,B_t,z_t) = A(t)D(y_t,x_t,B_t,z_t) \forall t$. Taking the geometric mean avoids imposing this restriction or arbitrarily choosing one of the two technologies.

3. CAPACITY UTILIZATION AND CAPITAL UTILIZATION

Productivity measures can be biased if variations in capacity utilization (CU) or capital utilization are not taken into account (Jorgenson and Griliches 1968, Morrison 1985). This discussion has focused on the fluctuation of economic activity over the business cycle, so that flows of services from the capital stock are not always proportional to the capital stock itself. With highly mobile fish, an additional spatial source of variation is introduced into utilization of the capital stock, the variation in time spent by the capital stock–the vessel, equipment, and gear–in searching for the resource prior to exploitation. This additional utilization, in turn, varies according to the fluctuations in demand, abundance and availability of fish and changes in the environment. The approach of Jorgenson and Griliches (1968) incorporates the utilization of capital by measuring capital in the production technology as utilized capital, rather than simply assuming that capital services are proportional to the capital stock.[8]

3.1 Calculation of the Malmquist Productivity Index

To calculate the index, we calculate the four component output distance functions, which will involve four linear programming programs for each producer in each pair of adjacent time periods. For example, the constant-returns-to-scale and output-oriented linear programming specification used to calculate $D_t(y_t,x_t,B_t,z_t)$ for each firm *k* is (Färe, Grosskopf and Roos 1995):

$$[D_t(y_t,x_t,B_t,z_t)]^{-1} = \max_{\phi,\underline{\lambda}} \phi, \qquad (4)$$

subject to:

$$\begin{aligned} -\phi y_{kt} + y_t\lambda &\geq 0 \\ x_{kt} - x_t\lambda &\geq 0 \\ B_{kt} - B_t\lambda &\geq 0 \\ z_{kt} - z_t\lambda &\geq 0 \\ \lambda &\geq 0 \end{aligned}$$

where λ are intensity variables which form the convex combinations of observed inputs and outputs, biomasses of fish stocks and environmental variables, such as the SSTs, thereby forming the piecewise linear best-practice reference technology. The intensity variables provide the (variable) weights given to each activity or observation to which observed points are compared.

The remaining three linear programming programs are simple variants of this distance function, $[D_{t+1}(y_{t+1},x_{t+1},B_{t+1},z_{t+1})]^{-1}$, $[D_t(y_{t+1},x_{t+1},B_{t+1},z_{t+1})]^{-1}$, $[D_t(y_t,x_t,B_t,z_t)]^{-1}$ and $[D_{t+1}(y_t,x_t,B_t,z_t)]^{-1}$.[9] If there are K firms with T time periods, we need to calculate (3T-2) LPs for each firm (that is K*(3T-2) LPs in the sample). The technology and the associated distance functions are independent of the units of measurement.

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[8] Capital is a flow of services given by multiplying the capital stock by the amount of utilization. This Jorgenson-Griliches (1968) framework is based on capital utilization, rather than on capacity utilization (CU). It assumes that only a single stock of capital determines capacity, and does not recognize the importance of fixity for establishing the value of capital (or other fixed inputs). Instead, it directly adjusts the quantity of capital for utilization. Since there is utilization of a single capital stock, capacity and capital utilization are basically the same.

[9] See, for example, Färe *et al.* (1994), Färe, Grosskopf and Roos (1995) and Grosskopf (2003), who also discuss the issues associated with mixed-period distance functions.

TABLE 1

Annual summary statistics of the data per vessel, 1997-2002

Variable	1997	1998	1999	2000	2001	2002
Skipjack catch (tonnes)	3 599	4 063	3 734	4 549	4 751	5 371
Yellowfin and bigeye catch (tonnes)	1 542	2 337	1 292	1 114	1, 463	743
Vessel carrying capacity (tonnes)	1 318	1 318	1 318	1 318	1 318	1 318
Days fished and searched	240	277	281	241	257	265
Vessel carrying capacity x days searched	315 777	364 365	370 373	317 455	338 644	348 711
Sea-surface temperature (°F)	85.59	84.30	83.80	83.60	84.90	83.68
Skipjack biomass (tonnes)	2 011 169	3 036 725	4 546 500	3 434 138	2 876 063	2 787 675
Yellowfin biomass (tonnes)	517 188	488 124	439 500	416 545	376 969	374 304
Bigeye biomass (tonnes)	96 511	83 851	84 445	76 633	80 843	65 009

The sample consists of 25 vessels for each year. °F = (°C x 1.8) + 32. The values in the last three lines are the averages of the exploitable biomasses for the fish available to the fishery for tunas associated with floating objects and that for free-swimming schools of tunas.

3.2 Empirical specification

The vector of inputs, $\underline{x}_t$, comprises the vessel's (plant's) capital stock, measured in carrying capacity, and fishing effort, measured in the number of days spent searching for fish. Fishing effort is not typical in production analyses, but it is consistent with the way managers and fishery scientists represent variable inputs (Kirkley, Squires and Strand 1995). Fishing effort thus represents energy, materials and labor inputs, and is used because more explicit input measures, such as labor or fuel, are unavailable.[10] The flow of capital services is measured as the product of carrying capacity and fishing effort, following the Jorgenson-Griliches (1967) approach to account for capital utilization. The measures of resource abundance are exploitable biomasses for all purse-seine vessels that fish in the WCPO for skipjack, yellowfin and bigeye tunas. Environmental conditions are captured by measures of SST in degrees Fahrenheit, where SST affects the aggregation of tunas in the PacificOcean (Sund, Blackburn and Williams 1981).

Output or catch is specified as tonnes of yellowfin and/or bigeye tunas as one output and tonnes of skipjack tuna as the second output. Yellowfin and bigeye tunas are not always recorded separately, as the juveniles, which make up the majority of the purse-seine catches, are similar in appearance. The catches of yellowfin far excced those of bigeye, so mixed catches of the two species are often recorded as yellowfin. Hence, because of measurement error, we linearly aggregated yellowfin and bigeye catches into one output. Skipjack are clearly distinguishable from yellowfin or bigeye, and the prices paid for skipjack are les than those paid for yellowfin and bigeye, so the catches of this species are always recorded separately.

3.2.1 Data

The analysis uses individual vessel-level data and fishing effort data for catches in the WCPO. The catch, fishing effort (number of days spent searching for fish), vessel carrying capacity and estimates of abundance of the three species of tuna were provided by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC). The years during which a vessel fished were determined from logsheet data held by the OFP. Insufficient information is available to determine whether carrying capacity, which was initially reported to the FFA, may have changed during the time period covered (1997-2002) so that the carrying capacities of the vessels were assumed to have been the same during each year, even though some vessels may have been "stretched" to increase their carrying capacities).

Campbell and Hand (1998) argue that all inputs are effectively fixed once the vessel puts to sea. Catch, then, depends on the intensity of factor use during the time period, which is measured by the number of sets made multiplied by the quantity of the fixed factor, *i.e.* services flow.

Exploitable biomass estimates for the purse-seine fishery for skipjack, yellowfin and bigeye, tunas, which were provided on a quarterly basis by the OFP[11], are based on the stock assessments (Langley, Ogura and Hampton 2003, Hampton and Kleiber 2003 and Hampton *et al.* 2003). The quarterly estimates were converted into annual estimates by summing the quarterly catches for each year. The vessel-level catch and effort data, which are collected by the OFP, pertain to the operations of the Korean fleet throughout the WCPO. The vessel carrying capacity data, also provided by the OFP, were combined with the catch and effort data to provide the panel data set. The SSTs for each set of the nets are taken from the logbooks of United States purse-seine vessels that operate west of 150°W latitude. The arithmetic average of these SSTs for all sets of all vessels in all areas of the WCPO are used as mean annual SSTs.[12]

In this section we use the methodology and data outlined in the Sections 2 and 3 to estimate changes in the productivity of the Korean tuna purse-seine fleet operating in the WCPO during 1997-2002 following Equation (3).

3.2.2 Growth in productivity, technology and technical efficiency

The empirical results indicate that the mean annual growth in MFP was marginally positive at 0.3% (Table 2).[13] This MFP growth was due entirely to technical change or process innovation (3.4%), since there was mean technical efficiency regresion of -3.0%. Thus, the managers or captains of the best-practice vessels continued to innovate with the adoption of improved vessel electronics or brailing systems, while the managers or captains of the other vessels failed to keep up with the innovations of the best-practice vessels. The results also demonstrate the variability of productivity growth across vessels, even within the same flag fleet.

Technical change represents the adoption of process innovations by the best-practice vessels of that production process.[14] Technical efficiency change represents the combined effects of at least two factors. First, process innovations, such as fishing for tunas associated with FADs or improved brailing systems tend to diffuse at different rates within a fleet, so that the change in technical efficiency captures, in part, the

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[11] Pers. com., John Hampton, Manager, Oceanic Fisheries Programme, Secretariat of the Pacific Community (2004).

[12] Sea-surface temperature (SST) was selected, in part, due to data availability. The logbooks of the vessels contain SST records for almost every set. Temperature affects the location and growth of primary producers (phyto- and zooplankton) upon which forage fish (*e.g.* small pelagic fish) feed. In turn, predators living higher on the food web, such as tunas and billfishes, feed upon these forage fish. Moreover, aggregation of the components of the food web occurs along temperature breaks in the ocean. That is,variation in the SSTs in the ocean are not always gradual; instead, there are abrupt temperature breaks. Other environmental variables were not readily available from this or other data sources.

[13] Subtracting 1 from a number in a table gives average increase or decrease per annum for the relevant time period and performance measure (Färe *et al.* 1994). Multiplying by 100 then gives the percentage of annual change. The results are reported as symmetric geometric means, which is standard for Malmquist productivity measures and is what is routinely calculated by two of the best-established software packages, DEAP and OnFront. It is also suggested by economists such as Coelli *et al.* (2005: 304-306). We used OnFront, and simply applied its results, following conventional practice. The asymmetrically-weighted geometric mean issue will be one for future research, as a referee suggests.

[14] Matsumoto *et al.* (2000) and Shono *et al.* (2000) observed that most of the introduction or improvement in vessel electronics were made around 1990-1991, so that much of these innovation effects on productivity growth may have already been accounted for by 1997, which was the initial year of the period covered by the study. Nonetheless, although there have not been many advances in "new" types of electronics in the last decade, significant improvements have occurred in traditional gear, particularly for sonar systems that are now closely integrated with GPS and Doppler current readings and for SIMRAD sonar systems in attempts to integrate computers to assist with species and size discriminations. The application of satellite technology has also played a role (Itano 2003). Another innovation is the introduction of Spanish style brailing (the catch handling and processing system), in which catches are brailed directly to recirculating brine holds cooled to approximately –9°C by ammonia compressors and held in the same hold until unloaded or transshipped; this gives faster fishing operations and the potential for more sets per day and greater catches before spoilage.

TABLE 2
Annual decomposition of multifactor productivity change accounting for capital utilization

	Technical efficiency change	Technical change	Multifactor productivity change
1997-1998	0.928	1.136	1.053
1998-1999	1.079	0.760	0.821
1999-2000	0.964	1.184	1.142
2000-2101	0.939	1.156	1.085
2001-2002	0.947	1.000	0.947
Mean	0.970	1.034	1.003

MFP and technical efficiency change are calculated relative to a constant-returns-to-scale technology following Equation (2), so that its interpretation is that it captures the change in maximal average product between t and t+1 (Grosskopf 2003). The annual values are geometric means of individual vessel values, and the overall mean is the geometric mean over the individual years.

TABLE 3
Cumulative (chained) multifactor productivity with adjustment for capital utilization

	Technical efficiency change	Technical change	Multifactor productivity change
1997	1.000	1.000	1.000
1998	0.928	1.136	1.053
1999	1.001	0.863	0.864
2000	0.965	1.022	0.987
2001	0.906	1.182	1.071
2002	0.859	1.181	1.014

TABLE 4
Effects of natural resource stock and state of the environment upon annual aggregate multifactor productivity (MFP) growth

	MFP	MFP without resource stock	MFP without environmental effect	MFP without resource and environment
1997-1998	1.053	1.251	1.053	1.506
1998-1999	0.821	0.751	0.821	0.872
1999-2000	1.142	1.192	1.141	1.261
2000-2001	1.085	1.059	1.085	0.903
2001-2002	0.947	0.833	0.947	1.136
Mean	1.003	0.997	1.003	1.112

The annual values are geometric means of individual vessel value, and the overall mean is the geometric mean over individual years.

rate of diffusion of the innovation. (Diffusion occurs by number of vessels and, for FAD fishing, numbers of FADs deployed and sets on FADs by a given vessel.) For example, when diffusion is comparatively slow, the laggards will tend to innovate more slowly than the best-practice vessels and hence will "fall behind" the expanding best-practice frontier defined by the innovation (Nishimizu and Page 1982). Second, technical efficiency change is also, in part, capturing changes in learning by doing (such as finding fish) with the diffused innovation, *i.e.* gaining proficiency with the diffused process innovation. This notion of a dynamic component to fishing skill extends the static concept of fishing skill identified by Kirkley, Squires and Strand (1998) with technical efficiency.

Cumulated (chained) productivity change during 1997-2002 progressed by 1.4%. This productivity progress was due entirely to cumulative technical change or process innovation of 18.1%, which outweighed cumulated technical efficiency regression of 14.1% (Table 3).

After accounting for the effects from varying environmental conditions and the effects of changes in resource abundance, the picture emerges of some vessels innovating, thereby shifting out to the best-practice frontier and other vessels not innovating or innovating at a much slower rate. Comparatively little learning takes place for the vessels failing to "catch up" with the expanding best-practice frontier.

3.2.3 Malmquist multifactor productivity and CPUE

Contrasting the Malmquist annual MFP growth, which control for the effects of changes in SST and biomasses and include the effects of all inputs, with changes in the annual nominal values of catch per unit effort (CPUE). They are simple partial productivity measures, providing strikingly dissimilar results (Figure 1). (The CPUE values are catches per day of searching, and are based on the vessels that are included in the data set used in the analysis.) The nominal CPUE values for the 1997-2000 period display large swings, as the nominal CPUE increased substantially between 1997 and 1998, declined between 1998 and 1999 and then increased again between 1999 and 2000. In contrast, the MFP changes between 1997 and 2000 were much more muted, particularly between 1997 and 1998. The estimated cumulative MFP change during the 1997-2002 period was 1.4%, that is, it is estimated that the 2002 the MFP of the Korean purse seine fleet was only 1.4% greater than it was in 1997. In contrast, the nominal CPUE was about 29% greater in 2002 than in 1997 (Figure 2).

FIGURE 1

Annual changes in nominal CPUE and MFP of the Korean purse-seine fleet in the WCPO during 1997-2002

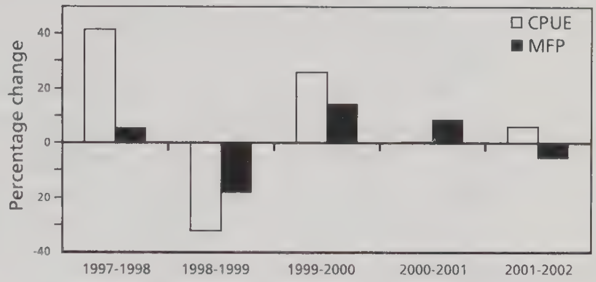
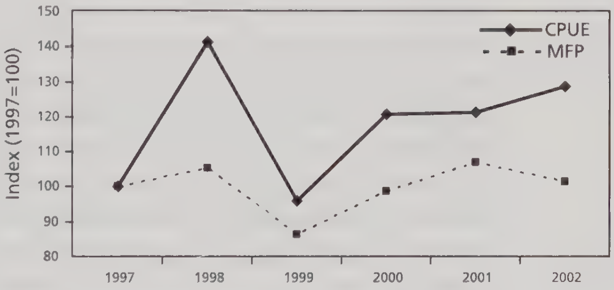


FIGURE 2

Cumulative changes in nominal CPUE and MFP of the Korean purse-seine fleet in the WCPO during 1997-2002



As previously outlined, the annual mean MFP growth for the Korean purse-seine fleet during the 1997-2000 period was marginally positive at just 0.3%. When the natural resource stock and environmental condition variables are excluded, the mean annual progress rates of aggregate productivity are -0.3% and 0.3%, respectively. However, excluding both the natural resource stock and the environmental variables gives an annual progress rate of aggregate productivity of 11.2%, illustrating the bias and misleading results that would otherwise result (Table 4). Accounting for changes in the abundance of natural resource stocks and the state of the environment reduces the mean annual overall multifactor productivity growth from 11.2% to 0.3%.

4. CONCLUDING REMARKS

This paper demonstrates that measures of multifactor productivity growth in natural resource industries are biased unless changes in the abundance of the fish stocks stocks and the effects of changes in the environment are taken into account. Furthermore, all changes in inputs over time must be taken into account to obtain complete and unbiased measures of productivity. Productivity measures such as CPUE, which that take into account only a single input (effort), provide incomplete measures of growth in productivity over time. This paper also presents a non-parametric method of measuring multifactor productivity, using a distance function, the Malmquist index, which readily accounts for unpriced changes in the resource stock and environment, and which does not require cost data. The approach was applied to a group of Korean purse-seine vessels that fish for tunas in the WCPO, where only modest growth of multifactor productivity was found, even though the CPUE increased substantially.

Productivity growth is one of the most important, if not the most important, determinants of the growth in fishing capacity over time, and represents one of the key challenges to managing fisheries. Without accurate measures of productivity growth in fishing industries, the extent of the excess capacity in global fisheries cannot be properly assessed, and appropriate conservation and management policies cannot be formulated.

The results are also of considerable political importance. The Republic of Korea, the United States and Japan, are high-cost producers of purse seine-caught tuna in the WCPO, and their continued competitiveness–and hence continued presence as flag-state vessels–depends, in part, on continued productivity growth. The lower-cost producers e.g. Chinese Taipei and the Peoples Republic of China, may otherwise overtake them, and thereby increase the the presence of those flag states in the WCPO.

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Relating estimates of fishing capacity obtained from Data Envelopment Analysis to traditional measures of fishing capacity

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ABSTRACT

Estimates of fishing capacity, *i.e.* the capacity to remove fish from a stock, are provided by readily available data such as gross registered tonnages (GRTs), fish-carrying capacities or lengths of the vessels, or even the numbers of vessels. Data envelopment analysis (DEA) of potential catch provides estimates of fishing capacity that are more consistent with the formal economic definition of fishing capacity, but much more detailed data are required to carry these out. In this paper, estimates of the fishing capacity of United States purse-seine vessels that operated in the western and central Pacific Ocean during 1983-2002 obtained from GRT data and DEA are compared. The two estimates are positively, but weakly, correlated, indicating that estimates of fishing capacity obtained from GRT data are of limited value.

1. INTRODUCTION

The notion of fishing capacity continues to generate substantial differences in opinion regarding its definition and, more generally, its conceptual meaning. In its broadest usage, capacity refers to the maximum amount something can contain. Capacity, in its widespread usage among policy makers, industry and other stakeholders, often refers to a measure of the capital stock, so that the capital stock is used as an indicator of the capacity base. Measures of the capital stock used as measures of capacity include gross registered tonnage (GRT), fish-carrying capacity, vessel length and even vessel numbers. Capacity has very precise and several alternative definitions and measures within the economics literature (Morrison 1985, Nelson 1989) and in its application to fishing and other natural resource industries (FAO 1998 and 2000, Kirkley and Squires 1999). The formal FAO definition (FAO 2000) is, "Fishing capacity is the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology. Fishing capacity is the ability of a vessel or vessels to catch fish." Broadly speaking, economic theory, national governments and the formal FAO definition of fishing capacity measure the capacity base by a measure of potential output or catch.[1]

The question that arises is how closely does capacity measured by the capital stock correspond to the FAO definition of fishing capacity as a measure of potential catch? A reasonably close correspondence between the capital stock and fishing capacity measured by potential catch would suggest that measures of the capital stock can be accurately used, or that they can be used interchangeably, but a distant correspondence would suggest that caution be exercised.

Specifically, the question that is empirically evaluated in this paper is how well do estimates of capacity output by data envelopment analysis (DEA), providing a measure of the capacity base, compare to changes in a readily available measure of the capital stock? If there is a close relationship between capacity output and the capital stock, then empirical evidence is provided that changes in the capital stock track changes in capacity output and that measures of the capital stock provide reasonably accurate measures of fishing capacity, *i.e.* of capacity output. If there is not a close relationship, then the empirical evidence does not support use of the capital stock as a surrogate measure of the capacity base, rather than capacity output. In either instance, the evidence provided is from a single fleet.

The fleet that is evaluated is the United States tuna purse-seine fleet, using annual data for vessels with at least 98 days absence during the year in question in the western and central Pacific Ocean over the 1983-2002 period. Gross registered tonnage (GRT) serves as the measure of the capital stock. Yellowfin and bigeye tuna caught in either unassociated schools or in schools associated with drifting floating objects are specified as one output and skipjack tuna caught in either of the two types of schools is specified as the second output. Both outputs were further specified on a per-day basis by dividing annual catch for each output by the total number of days absent.

2. EMPIRICAL ANALYSIS

The analysis proceeds in two steps. The first step estimates capacity output by DEA, which is described in greater detail below. The second step regresses capacity output per day on GRT plus a constant term. The better the fit of the regression analysis, then the closer the correspondence between potential catch and the capital stock for the fishery analyzed. This regression analysis is conducted for ten different functional forms described in the next section.

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[1] In economics, there are both primal and dual measures of potential output. In other words, potential output can be measured as a maximum potential output that can be produced, given that all variables are fully utilized and given the capital stock, or it can be measured as the short-run cost-minimizing, profit-maximizing or revenue-maximizing output levels. In fisheries, the primal or maximum potential output [illegible]

2.1. Regression analysis of capacity output and capital stock

The simplest functional form is linear, which can be specified as follows:

$$y = \alpha + \beta K + \varepsilon \tag{1}$$

where y denotes potential catch or capacity output per day, K denotes the capital stock as measured by GRT, α is the constant term, β denotes the coefficient for K or slope and ε denotes a random disturbance term.

Functional forms other than the linear form can describe the relationship between potential output (capacity output) and the capital stock (GRT). The logarithmic functional form can be written as:

$$y = \alpha + \beta \ln K + \varepsilon \tag{2}$$

where *ln* denotes the natural logarithm.

The quadratic functional form may be written:

$$y = \alpha + \beta_1 K + \beta_2 K^2 \tag{3}$$

The cubic functional form may be written:

$$y = \alpha + \beta_1 K + \beta_2 K^2 + \beta_3 K^3. \tag{4}$$

The exponential functional form may be written:

$$y = \alpha e^{\beta K} \tag{5}$$

The power functional form may be written:

$$y = \alpha K^{\beta} \varepsilon \tag{6}$$

The inverse functional form may be written:

$$y = \alpha + \beta \frac{1}{K} + \varepsilon \tag{7}$$

The logistic functional form may be written:

$$y = \frac{1}{1 + \beta e^{K}} \tag{8}$$

The compound functional form may be written:

$$h\ y = \ln \alpha + h\ \beta K + \varepsilon \tag{9}$$

The S functional form may be written:

$$h\ y = \alpha + \beta \frac{1}{K} + \varepsilon \tag{10}$$

2.2. Estimate of capacity output from data envelopment analysis

For the purpose of estimating capacity, an output-oriented DEA problem is solved. We desire to determine the maximum potential output levels that can be produced, given existing fixed factors (here, critically, the capital stock) and the potential level of variable inputs. Capacity for each observation is estimated by solving one mathematical programming problem (in actuality, a linear programming, LP, problem) for each observation. This facilitates the determination of a best-practice frontier, and permits capacity to be estimated for each observation. The basic LP problem is as follows:

$$TE_{ocj} = \underset{\theta, z, \lambda}{Max}\, \theta \tag{11}$$

subject to $$\theta u_{jm} \le \sum_{j=1}^{J} z_j u_{jm}, m = 1,\dots, M,$$

$$\sum_{j=1}^{J} z_j x_{jn} \le x_{jn}, n \in F_x$$

$$\sum_{j=1}^{J} z_j x_{jn} = \lambda_{jn} x_{jn}, n \in V_x$$

$$\sum_{J} z_{J} = 1.0$$

$$z_J \ge 0, j = 1,2,\dots, J$$

$$\lambda_{jn} \ge 0,$$

where θ (2 \$ 1.0) is a measure of technical efficiency, TE, and is the inverse of an output distance function; F is a vector of fixed inputs; V is a vector of variable inputs; z is a vector of intensity variables used to construct the piece-wise technology; and u is a vector of outputs. If we multiply the observed output by 2, we obtain an estimate of capacity output. Capacity can also be estimated by solving the same problem without the variable input constraints, which indicates that they are, in fact, decision variables. With either the equality constraint included on the variable inputs or the omission of the variable inputs, the solution to problem (11) yields values of z that can then be used to calculate the level of variable inputs required to produce the capacity output.

Problem (11) imposes strong disposability in outputs and variable returns to scale. Strong disposability imposes the assumption that a producer (vessel operation) has the ability to dispose of any unwanted commodities without incurring any production cost or experiencing a loss in revenue. Variable returns to scale imposes the assumption that increasing all inputs by the same proportion will cause outputs to change by varying proportions (*e.g.* if all input are doubled, output levels might increase by a factor of 2, less than 2 or more than 2). The important aspect of variable returns to scale is that it permits varying rates of change in output levels, given different rates of change in input levels. The constraint that the sum of $z_j = 1.0$ imposes variable returns to scale.

Färe *et al.* (1989) initially proposed the DEA specification given in problem (1) for assessing capacity when data were limited to input and output quantity information. In other words, economic data such as cost and earnings information and information on input and output prices were not available. Problem (1) is a technological-engineering concept of capacity, but since estimates are based on actual data, estimates of capacity obtained from solutions to problem (1) implicitly reflect the underlying economics.

In addition to obtaining an estimate of capacity, problem (11), together with the same problem, but including all inputs, may be used to estimate an unbiased measure of capacity utilization (CU). Färe *et al.* (1989) demonstrated that the ratio of an output-oriented measure of TE (TE_{oj}), with fixed and variable inputs included, to an output-oriented measure of TE (TE_{ocj}), with variable inputs excluded, yielded a relatively unbiased measure of CU:

$$\text{CU}_\text{j} = \frac{\text{TE}_{\text{oj}}}{\text{TE}_{\text{ocj}}} \tag{12}$$

The CU measure of Färe *et al.* (1989) permits an assessment of whether deviations from full capacity are because of inefficient production or less than full utilization of the variable and fixed inputs.

The relationship between capacity output (estimated by DEA) and the capital stock, the latter measured by GRT, for the entire fleet is supplemented by a more disaggregated analysis for disaggregated groupings of vessels as defined by cluster analysis. The premise is that analysis with more finely tuned groups of data might reveal finer resolution of the results than a more aggregated analysis. Since this analysis is simply a "first-cut" analysis, further investigation of the relationship between capacity output and the capital stock can define more systematic classifications of the vessels.

An additional analysis of the relationship between capacity output (estimated by DEA) and capital stock, measured by GRT, includes the variables for biomass of the target species and sea-surface temperature to control the influence of the environment and an annual time trend. In this case, with a linear functional form, the regression analysis is written as:

$$\begin{aligned} y = \beta_0 + \beta_1 \mathrm{GRT} + \beta_2 \mathrm{BiomassYellowfinBigeye} + \beta_3 \mathrm{BiomassSkipjack} + \\ \beta_4 \mathrm{SeaSurfaceTemperature} + \beta_5 \mathrm{Trend} + \varepsilon \end{aligned} \qquad (13)$$

3. EMPIRICAL RESULTS

The result of regression of total capacity output per day, calculated as the sum of the individual capacity outputs per day, upon the measure of the capital stock, GRT, is reported in Table 1 for the ten alternative functional forms considered (Equations 1-10) and illustrated in Figure 1.

The regression results (Table 2) indicate a statistically significant overall regression for each functional form (Equations 1-10), as indicated by the F-statistic, but a very weak fit, as indicated by the R^2 of regression. Some of the functional forms gave marginally superior results, as indicated by the overall F-statistic for significance of regression and the R^2, but the overall results remain weak. Considerable dispersion around the fitted regression line can be seen in Figure 1, reinforcing the notion that there is only a limited

FIGURE 1

Observed and fitted values of total (yellowfin, bigeye, and skipjack) capacity output per day obtained from DEA vs. gross registered tonnage, with different functional forms

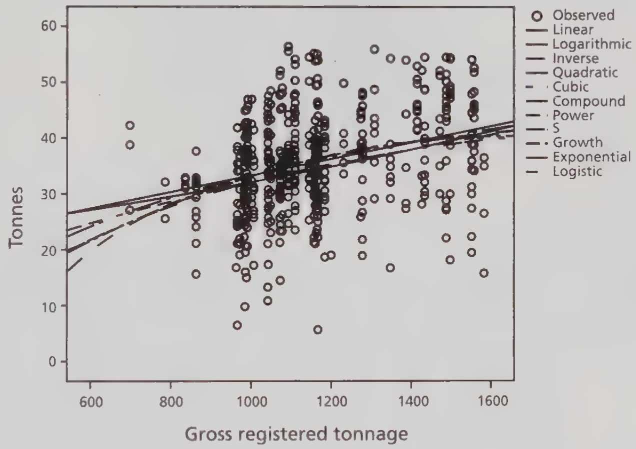


TABLE 1

Regression of total capacity output per day against GRT, given different functional forms

Functional form	R square	Degrees of freedom	F	Significance	β₀	β₁	β₃	β₄
Linear	0.090	498	49.40	0.000	18.4997	0.0148		
Logarithmic	0.093	498	50.94	0.000	-89.798	17.8097		
Inverse	0.092	498	50.60	0.000	53.6528	-20376		
Quadratic	0.096	497	26.31	0.000	-5.9402	0.0560	-2×10^{-5}	
Cubic	0.097	497	26.64	0.000	-1.998	0.0385		-5×10^{-9}
Compound	0.070	498	37.58	0.000	21.0888	1.0004		
Power	0.073	498	38.97	0.000	0.9682	0.5065		
S	0.072	498	38.89	0.000	4.0481	-580.69		
Growth	0.070	498	37.58	0.000	3.0487	0.0004		
Exponential	0.070	498	37.58	0.000	21.0888	0.0004		
Logistic	0.070	498	37.58	0.000	0.0474	0.9996		

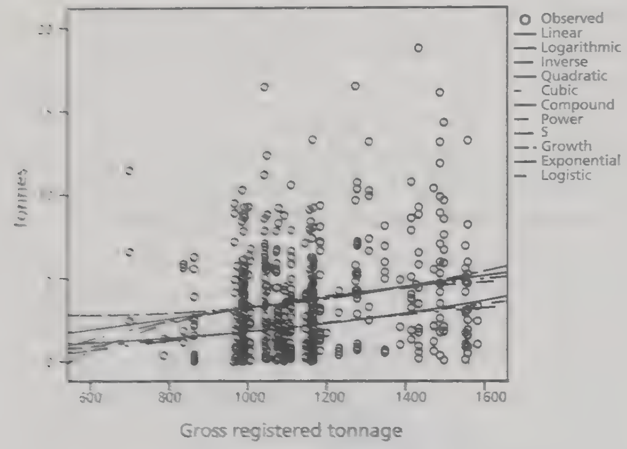
The total capacity output per day is the sum of the capacity output per day of yellowfin and bigeye plus the capacity output per day of skipjack.

TABLE 2
Statistical results of regressions of total capacity output per day absent against independent variables

Variable	Unstandardized coefficients		Standardized coefficients	t-statistic	Significance
	Coefficient β	Standard error	Beta		
Constant	111.273	403.672		0.276	0.783
GRT	0.015	0.002	0.306	9.409	0.000
Biomass of yellowfin and bigeye	0.000	0.000	0.605	7.110	0.000
Biomass of skipjack	0.000	0.000	0.714	10.516	0.000
Sea-surface temperature	2.368	0.883	0.167	2.683	0.008
Year	-0.176	0.183	-0.076	-0.961	0.337

Note: adjusted R-square = 0.473.

FIGURE 2
Observed and fitted values of yellowfin and bigeye capacity output per day obtained from DEA vs. gross registered tonnage, with different functional forms



statistical relationship. Eight of the ten equations indicated a positive coefficient for GRT. The only exceptions are the inverse and S functional forms, Equations (7) and (10), respectively, in which the capital stock enters as the inverse and in which the expected sign of the coefficient for capital stock is negative, as expected. These results for all equations suggest a positive relationship between the capital stock and total capacity output per day. In sum, a statistically significant and positive relationship exists between total capacity output and the capital stock, but the result is so weak that it indicates no close association between the two. Regression of total capacity output per day for yellowfin and bigeye, illustrated by Figure 2, reinforces this conclusion.

Total capacity output regressed against the explanatory variables of Equation (13) indicated a much stronger relationship, with an adjusted R^2 of 0.473 and a statistically significant overall F-statistic of 90.869 (degrees of freedom = 5, 495). The coefficient for GRT was positive, as expected, and statistically significant, thereby suggesting a positive relationship between the capital stock and total capacity output. This relationship reinforces the previous conclusion that a positive, but weak, relationship exists between the two. In addition, as expected, greater biomasses increase total capacity output per day, given GRT, indicated by the statistically significant and positive regression coefficient. A higher sea-surface temperature also increases total capacity output per day, indicated by the statistically significant and positive regression coefficient.

Disaggregated analysis of the relationship between capacity output and capital stock (GRT) by vessel size groups determined by cluster analysis indicates a stronger relationship between the two (Tables 3-17).

Tables 3, 4, 5, 6, 8, 10, 12, 14 and 16 summarize total capacity output, GRT, and other related statistics for each of the five clusters and overall. Tables 7, 9, 11, 13 and 15 summarize the results for the regression of total capacity output on the capital stock or GRT for Clusters 1, 2, 3, 4 and 5, respectively, for the functional forms given by Equations (1)-(10). Table 17 summarizes the analysis of variance results for differences

TABLE 3

Summary statistics of cluster analysis

Cluster	Min. GRT	Max. GRT	Mean GRT	Median GRT	SE of mean	Min. total Q	Max. total Q	Mean total Q	Median total Q	SE total Q
3	698	863	828.6	863	12.34	15.62	42.26	29.97	31.38	1.27
2	963	1078	1016.9	1002	2.75	0.00	52.04	32.69	33.56	0.64
4	1093	1231	1146.1	1160	2.64	5.66	56.39	36.41	35.64	0.67
5	1274	1434	1354.6	1348	8.05	16.72	55.92	39.28	39.33	1.11
1	1472	1583	1521.7	1498	4.80	15.76	54.50	39.88	41.24	1.32

TABLE 4

Estimated capacity outputs by cluster

Cluster	Mean GRT	YFT+BET CCPDA, unassociated schools	SKJ CCPDA, unassociated schools	YFT+BET CCPDA, floating-object schools	SKJ CCPDA, floating-object schools
3	828.59	4.57	12.31	3.76	9.33
2	1016.90	4.54	13.66	3.77	10.72
4	1146.12	4.48	14.65	4.22	13.06
5	1354.60	6.66	15.06	4.48	13.09
1	1521.70	6.49	15.28	4.51	13.60

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 5

Summary of mean GRT, observed (obs.) output, capacity output, and ratio (mean of ratios) of capacity to observed output

Cluster	Mean GRT	YFT+BET CCPDA, unassociated schools			SKJ CCPDA, unassociated schools		
		Capacity output	Obs. output	Ratio	Capacity output	Obs. output	Ratio
3	828.59	4.57	2.91	1.57	12.32	7.90	1.56
2	1016.87	4.54	3.18	1.43	13.66	9.22	1.48
4	1146.12	4.48	2.94	1.52	14.65	9.44	1.55
5	1354.62	6.66	5.03	1.32	15.06	11.69	1.29
1	1521.66	6.49	4.61	1.41	15.28	11.10	1.38
Total	1154.18	5.03	3.50	1.44	14.30	9.77	1.46

TABLE 5 (continued)

Cluster	Mean GRT	YFT+BET CCPDA, floating-object schools			SKJ CCPDA, floating-object schools			Total capacity output		
		Capacity output	Obs. output	Ratio	Capacity output	Obs. output	Ratio	Capacity output	Obs. output	Ratio
3	828.59	3.76	2.66	1.41	9.33	7.05	1.32	29.97	20.53	1.46
2	1016.87	3.77	2.65	1.42	10.72	7.41	1.45	32.69	22.45	1.46
4	1146.12	4.22	2.82	1.50	13.06	8.83	1.51	36.41	23.82	1.53
5	1354.62	4.48	3.01	1.49	13.09	8.92	1.47	39.28	28.65	1.37
1	1521.66	4.51	2.84	1.59	13.60	8.21	1.66	39.88	26.76	1.49
Total	1154.18	4.10	2.77	1.48	12.07	8.08	1.49	35.49	24.13	1.47

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 6

Estimated capacity outputs for Cluster 1

	GRT	YFT+BET CCPDA, unassociated schools	SKJ CCPDA, unassociated schools	YFT+BET CCPDA, floating-object schools	SKJ CCPDA, floating-object schools	Total capacity output
Number of observations	59	59	59	59	59	59
Minimum	1472	0.00	0.00	0.00	0.00	15.76
Maximum	1583	16.08	36.21	15.62	45.89	54.50
Mean	1521.66	6.4922	15.2771	4.5098	13.5993	39.8785
Median	1498	5.9500	15.0100	3.6600	11.9300	41.2400
Standard error of mean	4.803	0.57754	1.20806	0.45772	1.48937	1.31737

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 7

Regression of total capacity output on capital stock for Cluster 1

Equation	Model summary					Parameter estimates			
	R square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.056	3.355	1	57	0.072	138.281	-0.065		
Logarithmic	0.055	3.321	1	57	0.074	758.351	-98.055		
Inverse	0.055	3.287	1	57	0.075	-57.856	148,632.794		
Quadratic	0.056	3.389	1	57	0.071	89.268	0.000	0.000	
Cubic	0.081	2.468	2	56	0.094	-2,925.078	2.953	0.000	0.000
Power	0.050	3.029	1	57	0.087	17,082,558,687.665	-2.718		
S	0.050	2.997	1	57	0.089	0.940	4,118.265		
Growth	0.051	3.062	1	57	0.086	6.376	-0.002		
Exponential	0.051	3.062	1	57	0.086	587.659	-0.002		
Logistic	0.051	3.062	1	57	0.086	0.002	1.002		

The independent variable is GRT and the dependent variable is total capacity output.

TABLE 8

Estimated capacity outputs for Cluster 2

	GRT	YFT+BET CCPDA, unasso-ciated schools	SKJ CCPDA, unasso-ciated schools	YFT+BET CCPDA, floating-object schools	SKJ CCPDA, floating-object schools	Total capacity output
Number of observations	191	191	191	191	191	191
Minimum	963	.00	.00	.00	.00	.00
Maximum	1078	16.44	31.27	11.77	40.43	52.04
Mean	1016.87	4.5446	13.6594	3.7701	10.7153	32.6893
Median	1002	3.4700	12.7900	3.5200	9.3000	33.5600
Standard error of mean	2.745	0.28773	0.62069	0.18837	0.61752	0.64259

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 9

Regression of total capacity output on capital stock for Cluster 2

Equation	Model summary					Parameter estimates			
	R square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.037	7.140	1	188	0.008	-11.050	0.043		
Logarithmic	0.037	7.261	1	188	0.008	-275.252	44.502		
Inverse	0.038	7.384	1	188	0.007	77.983	-45,814.383		
Quadratic	0.051	5.043	2	187	0.007	-1,111.089	2.197	-0.001	
Cubic	0.051	5.043	2	187	0.007	-1,111.089	2.197	-0.001	0.000
Power	0.033	6.327	1	188	0.013	0.001	1.500		
S	0.033	6.446	1	188	0.012	4.973	-1,545.883		
Growth	0.032	6.211	1	188	0.014	1.972	0.001		
Exponential	0.032	6.211	1	188	0.014	7.186	0.001		
Logistic	0.032	6.211	1	188	0.014	0.139	0.999		

The independent variable is GRT and the dependent variable is total capacity output.

TABLE 10

Estimated capacity outputs for Cluster 3

	GRT	YFT+BET CCPDA, unassociated schools	SKJ CCPDA, unassociated schools	YFT+BET CCPDA, floating-object schools	SKJ CCPDA, floating-object schools	Total capacity output
Number of observations	22	22	22	22	22	22
Minimum	698	0.03	0.00	0.51	2.85	15.62
Maximum	863	13.43	23.00	7.88	19.16	42.26
Mean	828.59	4.5727	12.3150	3.7559	9.3282	29.9718
Median	863	3.2400	11.6650	3.1050	8.4100	31.3750
Standard error of mean	12.344	0.88034	1.54917	0.41665	0.88131	1.27080

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 11

Regression of total capacity output on capital stock for Cluster 3

Equation	Model summary					Parameter estimates			
	R square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.177	4.294	1	20	0.051	65.834	-0.043		
Logarithmic	0.177	4.306	1	20	0.051	257.193	-33.827		
Inverse	0.177	4.314	1	20	0.051	-1.955	26,315.426		
Quadratic	0.177	2.045	2	19	0.157	96.218	-0.121	0.000	
Cubic	0.177	2.045	2	19	0.157	96.218	-0.121	0.000	0.000
Power	0.138	3.213	1	20	0.088	44,300.963	-1.090		
S	0.138	3.197	1	20	0.089	2.354	845.204		
Growth	0.139	3.227	1	20	0.088	4.538	-0.001		
Exponential	0.139	3.227	1	20	0.088	93.501	-0.001		
Logistic	0.139	3.227	1	20	0.088	0.011	1.001		

The independent variable is GRT and the dependent variable is total capacity output.

TABLE 12

Estimated capacity outputs for Cluster 4

	GRT	YFT+BET CCPDA, unasso-ciated schools	SKJ CCPDA, unasso-ciated schools	YFT+BET CCPDA, floating-object schools	SKJ CCPDA, floating-object schools	Total capacity output
Number of observations	164	164	164	164	164	164
Minimum	1093	0.00	0.00	0.00	0.00	5.66
Maximum	1231	14.79	33.94	15.62	45.89	56.39
Mean	1146.12	4.4753	14.6516	4.2222	13.0639	36.4130
Median	1160	3.8550	14.8100	3.5300	10.6900	35.6350
Standard error of mean	2.641	0.28856	0.72584	0.24970	0.84713	0.67383

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 13

Regression of total capacity output on capital stock for Cluster 4

Equation	Model summary					Parameter estimates			
	R square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.008	1.297	1	162	0.256	62.470	-0.023		
Logarithmic	0.008	1.328	1	162	0.251	221.833	-26.324		
Inverse	0.008	1.357	1	162	0.246	9.855	30,412.166		
Quadratic	0.012	0.974	2	161	0.380	573.458	-0.916	0.000	
Cubic	0.012	0.987	2	161	0.375	405.433	-0.472	0.000	0.000
Power	0.011	1.793	1	162	0.182	29,892.410	-0.957		
S	0.011	1.832	1	162	0.178	2.597	1,105.976		
Growth	0.011	1.751	1	162	0.188	4.510	-0.001		
Exponential	0.011	1.751	1	162	0.188	90.967	-0.001		
Logistic	0.011	1.751	1	162	0.188	0.011	1.001		

The independent variable is GRT and the independent variable is total capacity output.

TABLE 14

Estimated capacity outputs for Cluster 5

	GRT	YFT+BET CCPDA, unassociated schools	SKJ CCPDA, unassociated schools	YFT+BET CCPDA, floating-object schools	SKJ CCPDA, floating-object schools	Total capacity output
Number of observations	65	65	65	65	65	65
Minimum	1274	0.00	0.00	0.20	1.05	16.72
Maximum	1434	18.74	36.21	15.62	41.97	55.92
Mean	1354.62	6.6582	15.0560	4.4792	13.0874	39.2808
Median	1348	6.9200	14.8500	2.9300	11.6900	39.3300
Standard error of mean	8.053	0.56290	1.12953	0.45631	1.09950	1.11491

YFT = yellowfin; BET = bigeye; SKJ = skipjack; CCPDA = capacity catch per day absent.

TABLE 15

Regression of total capacity output on capital stock for Cluster 5

Equation	Model summary					Parameter estimates			
	R square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0.027	1.747	1	63	0.191	8.471	0.023		
Logarithmic	0.027	1.735	1	63	0.192	-181.683	30.646		
Inverse	0.027	1.723	1	63	0.194	69.791	-41,235.812		
Quadratic	0.029	0.912	2	62	0.407	290.407	-0.395	0.000	
Cubic	0.029	0.911	2	62	0.408	194.120	-0.184	0.000	0.000
Power	0.028	1.808	1	63	0.184	0.067	0.880		
S	0.028	1.789	1	63	0.186	4.517	-1,182.813		
Growth	0.028	1.827	1	63	0.181	2.755	0.001		
Exponential	0.028	1.827	1	63	0.181	15.721	0.001		
Logistic	0.028	1.827	1	63	0.181	0.064	0.999		

The independent variable is GRT and the independent variable is total capacity output.

TABLE 16

Mean GRT and capacity output per day and standard errors of mean values

Cluster and standard error	Mean GRT and standard error	Mean capacity output per day and standard error
Cluster 3	828.6	30.0
Standard error	12.3	1.3
Cluster 2	1,016.9	32.7
Standard error	2.7	0.6
Cluster 4	1,146.1	36.4
Standard error	2.6	0.7
Cluster 5	1,354.6	39.3
Standard error	8.1	1.1
Cluster 1	1,521.7	39.9
Standard error	4.8	1.3
Total	1,154.2	35.5
Standard error	8.3	0.4

TABLE 17

Analysis of variance for differences in total capacity output between clusters

Cluster	Coefficient β_i	Standard error	t-statistic	Significance
Constant	39.878	1.139	35.005	0.000
Cluster 2	-7.017	1.304	5.381	0.000
Cluster 3	-9.097	2.186	-4.532	0.000
Cluster 4	-3.465	1.328	-2.609	0.009
Cluster 5	-0.598	1.574	-0.380	0.704

The dependent variable is total capacity output. Cluster 1 is constant and Clusters 2-5 are dummy variables.

in total capacity output by GRT size class, as defined by the clusters, and indicates statistically significant differences among clusters.

The regression results of total capacity output on capital stock for Clusters 1-5 give very low values for the R^2 and the F-statistics for overall regression that are almost always not statistically significant at the 5-percent level, although it is significant at the 10-percent level for each of the functional forms. In summary, the disaggregated results at the level of individual GRT size classes does not materially improve the combined analysis, and, in fact, gives results that are not statistically significant.

4. CONCLUDING REMARKS

How closely does capacity measured by a vessel's capital stock correspond to the FAO definition of fishing capacity as a measure of potential catch? A reasonably close correspondence between the capital stock and fishing capacity measured by potential catch would suggest that measures of the capital stock can be accurately used, or that they can be used interchangeably, but a distant correspondence would suggest that caution be raised.

This chapter empirically evaluated how well estimates of capacity output by DEA, providing a measure of the capacity base, compare to changes in a readily available measure of the capital stock. For the sample of United States tuna purse-seine vessels analyzed, there is only a very limited relationship between GRT, as a measure of the capital stock, and the FAO definition of fishing capacity as a potential output or maximum potential catch. Further analysis of the potential relationship between vessel size groupings and capacity output should be conducted, if additional data on vessel characteristics can be obtained.

In summary, for the United States tuna purse-seine vessels analyzed, there is only a limited relationship between an individual vessel's capital stock, measured by its GRT, and that vessel's fishing capacity, estimated by DEA and following the FAO definition. For this fleet, at least, changes in the capital stock over time do not closely or accurately correspond to changes in fishing capacity over time, although there is a very limited positive relationship.

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Requirements and alternatives for the limitation of fishing capacity in tuna purse-seine fleets

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ABSTRACT

Most stocks of tunas are fully exploited, and two stocks, Atlantic bluefin and southern bluefin, are clearly overexploited. With the exception of skipjack, increased fishing effort for the principal market species of tunas will not result in sustained increases in catch, and would probably lead to reduced catches over the long term. It is clear that controls on the amount of fishing mortality exerted on most of the stocks of tuna are needed. Controls on tuna fishing are administered principally by five international organizations, the Inter-American Tropical Tuna Commission, the International Commission for the Conservation of Atlantic Tunas, the Indian Ocean Tuna Commission, the Commission for the Conservation of Southern Bluefin Tuna and the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean. Two types of controls are possible, input controls, such as restrictions on the numbers of fishing vessels or the periods during which fishing is permitted, and output controls, such as catch quotas or limits on the sizes of individual fish that can be retained. There is general agreement that input controls should be the principal method for limiting fishing mortality; specifically, fishing capacity must be limited. This can be accomplished in various ways. Regional vessel registers can limit the numbers and capacities of vessels permitted to fish in a region, and a global vessel register can limit the numbers and capacities of vessels permitted fish anywhere in the world. Such

limits can be in the form of use rights, which, under certain circumstances, should be tradeable. Buybacks of excess vessels can reduce or eliminate the economic hardships for the owners of vessels that are not permitted to fish. Limitations on fishing mortality can also be accomplished by quotas to nations or to vessel owners or by licensing. Quotas or licences can be bought and sold. During the initial phase of capacity limitation programs additional output controls may be needed to ensure effective management and conservation. Limitations on fishing capacity, regardless of how they are accomplished, are beneficial from the standpoints of both economics and conservation of tunas and other species caught by the fisheries for tunas.

1. BACKGROUND

Harvests of fish from the world's oceans have been relatively stable at about 85 million tonnes per year for the last decade (FAO, 2005). These harvests represent catches from hundreds of stocks of fish. Many of these stocks have been overfished, resulting in declining catches. The decreases in the catches of some stocks have been replaced by the development of fisheries on previously unexploited or lightly exploited stocks. It has been estimated by Garcia, de Leiva Moreno and Grainger (2005) that about 25 percent of the fish stocks making up the world catches of marine fish are overexploited and about 50 percent are fully exploited. The primary cause of this overexploitation of the world's fisheries has been attributed to the existence of more fishing capacity than is needed to harvest the available catch (Mace 1997). In fact, during the last three decades the world's fleet of active fishing vessels increased at a rate several times the rate of growth of world catches (Gréboval and Munro, 1999).

Because of this situation, and the resulting concern of nations over the deteriorating state of world fisheries, the FAO adopted an International Plan of Action for the Management of Fishing Capacity (IPOA-CAPACITY). The objective of the IPOA was for states and regional fisheries organizations to achieve worldwide, efficient, equitable and transparent management of fishing capacity, preferably by 2003, but not later than 2005. Though the target date of 2005 has passed and worldwide management of fishing capacity has not been established, many nations and regional fishery management organizations (RFMOs) have initiated programmes to address the problems associated with excess fishing capacity. Nevertheless, world fishing fleets continue to grow, and overfishing continues to exist.

Although at the outset, tuna fisheries have not been the specific objective of these initiatives, there has nevertheless developed considerable concern over growing fishing capacity in world tuna fleets and the impact of this on the tuna stocks.

1.1 World tuna fisheries and status of the stocks

The principal market species of tuna (skipjack, *Katsuwonus pelamis*; yellowfin, *Thunnus albacares*; bigeye, *T. obesus*; albacore, *T. alalunga*; and bluefins, *T. thynnus, T. orientalis* and *T. macoyii*) make up about 5 percent of the world's commercial production of marine species (FAO, 2005). Though not a large component of the world catch of fish in terms of tonnage, in terms of value tuna are a much more significant component of the total value of all marine fish caught. For nations like the Maldives, Ecuador and many of the Pacific Island States, tuna is one of the major components of their economy.

Prior to 1950 the world catches of tuna were less than 350 thousand tonnes annually, but at that time they began to increase, and continued to grow until around 1998, at which time the catch reached nearly 4 million tonnes (Miyake, 2005a). Since 1998 catches have fluctuated around that level. Most of the catch, about 60 percent, is taken by purse-seine vessels, with about 15 percent being accounted for by pole-and-line vessels, 15 percent by longline vessels and the remainder by a variety of other gear types.

With the exception of skipjack in some oceans, almost all of the principal market species of tunas are either fully exploited or overexploited (IATTC, 2003; ICCAT, 2003; Langley *et al.*, 2003; Joseph, 2004; de Leiva Moreno and Majkowski, 2005).

The bluefin tunas are the most heavily exploited of the principal market species. Catches of southern bluefin have declined from a high of 80 thousand tonnes in the early 1960s to current levels of about 15 thousand tonnes. The species is heavily overexploited, and increased fishing mortality will not result in sustained increases in catch; in fact, there is increasing concern over the possibility of recruitment failure for this species. The situation is similar for the Atlantic bluefin. In the western Atlantic the stock is considered to be heavily overexploited, and in the eastern Atlantic and Mediterranean the stock is below the level corresponding to the average maximum sustainable yield (AMSY). Bluefin in the North Pacific are probably fully exploited, but catches vary considerably due to natural fluctuations in abundance. Current harvests of the three species of bluefin have averaged about 60 thousand tonnes in recent years: 15 thousand for southern bluefin, 25 thousand for Atlantic bluefin and 20 thousand for North Pacific bluefin.

There are six stocks of albacore in the world's oceans: two in the Pacific, two in the Atlantic and one each in the Mediterranean Sea and the Indian Ocean. Four of these stocks are fully exploited, one is not fully exploited and the status of one is unknown. In recent years catches have averaged about 225 thousand tonnes, 140 thousand of which is from the Pacific, 60 thousand from the Atlantic and Mediterranean and the rest from the Indian Ocean.

Prior to 1980 most bigeye was captured by longline gear, which takes mostly large fish near the size that results in maximizing the yield per recruit. With the widespread use of fish-aggregating devices (FADs) by purse-seine vessels after the 1980s, large quantities of small bigeye have been caught. This reduced the overall yield per recruit and threatens growth overfishing of most of the bigeye stocks in the three oceans. World catches have averaged about 450 thousand tonnes in recent years: 230 thousand from the Pacific, 80 thousand tonnes from the Atlantic and 140 thousand from the Indian Ocean.

All yellowfin stocks are considered to be fully exploited, and increased fishing effort would not be expected to result in sustained increases in catch. Recent world catches of this species have averaged about 1.3 million tonnes, of which about 800 thousand tonnes are from the Pacific, 400 thousand tonnes from the Indian Ocean and 125 thousand tonnes from the Atlantic.

Skipjack comprise about 50 percent of the world catch of the principal market species of tuna. In recent years the average catch has been about 2 million tonnes per year. Of these 2 million tonnes, about 1.5 million are from the Pacific, about 450 thousand from the Indian Ocean and about 140 thousand from the Atlantic. The best scientific information suggests that skipjack in the eastern Atlantic Ocean may be fully exploited, but the stocks in other areas are probably not yet fully exploited, particularly in the western and central Pacific Ocean (WCPO).

In summary, with the exception of skipjack tuna, particularly in the Pacific, most stocks of tunas are fully exploited, and two stocks of bluefin are clearly overexploited. In general, increased fishing effort for most of these stocks will not result in sustained increases in catch, but would probably lead to reduced catches over the long term. It is clear that controls on the amount of fishing mortality exerted on most of the stocks of tuna are needed.

1.2 Conservation approaches

Tunas are a renewable resource, and the rate at which they are captured affects their abundance, and, therefore, their ability to sustain given levels of harvest. With increasing fishing pressure on the stocks of tuna it is necessary that conservation controls be initiated in order to keep exploitation at levels that will keep the populations at desired levels of abundance. Effective management of tunas is complicated, however, by the fact that they are great wanderers, and during the course of their lives they may pass through waters under the jurisdictions of many different nations. This mobility sets the management of tunas apart from that of less nomadic species, and requires that nations cooperate with each other if management is to be effective. Early in the negotiations to draft a convention on the law of the sea the nations of the world recognized the highly-migratory nature of the tunas. Article 64 of the United Nations Convention on the Law of the Sea (LOSC) mandates that states co-operate directly or through appropriate international organizations to ensure the conservation of highly-migratory species. More recently, other international instruments have been drafted to ensure that nations comply with the dictates of LOSC. In 1995 the Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Seas of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (UN Fish Stocks Agreement) was adopted by the United Nations. The objective of the UN Fish Stocks Agreement is to ensure that the relevant provisions of the LOSC are applied with respect to the management of the highly-migratory stocks of fish of the world, particularly with respect to cooperation among nations as envisioned in Article 64 of the LOSC. The UN Fish Stocks Agreement includes a number of new concepts, such as biodiversity and ecosystem management, transparency among stake-holders in developing conservation measures and the application of the precautionary approach that should be included in any proposed management measures. The FAO Code of Conduct for Responsible Fisheries provides further support for the application of the provisions of the LOSC and the UN Fish Stocks Agreement. These three international instruments have acted as catalysts for the implementation of measures to manage tunas.

Currently there are five international conventions for the establishment of Article 64-type tuna bodies in the world. Two of these tuna bodies, the Inter-American Tropical Tuna Commission (IATTC) and the International Commission for the Conservation of Atlantic Tunas (ICCAT), were created before Article 64 existed, and were used as case studies in formulating Article 64 and the subsequent instruments. The remaining three bodies, the Commission for the Conservation of Southern Bluefin Tuna (CCSBFT), the Indian Ocean Tuna Commission (IOTC) and the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Central and Western Pacific Ocean (WCPFC) were created more recently. All five of the regional tuna bodies have a similar objective of maintaining the stocks of fish for which they are responsible at or above levels of abundance that can support AMSYs. To achieve this objective, the bodies are empowered to coordinate and/or conduct research on the animals and fisheries for them, the results of which can be used to make recommendations to the high contracting parties for maintaining the populations at the desired levels of abundance. The degree to which the bodies have been successful in achieving their objectives has varied. The two oldest bodies, IATTC and ICCAT, were created before there was enough fishing capacity to cause overfishing problems. However, as the fishing capacity increased, controls to prevent overfishing were needed. The two most recent bodies, IOTC and WCPFC, were created before overfishing occurred, but the capacity of the fleets in the Indian Ocean and WCPO are currently increasing rapidly enough to cause overfishing. The CCSBFT was created in response to severe overfishing of the southern bluefin stock, and its fundamental charge was to increase the population to a level of abundance that would support the AMSY.

1.2.1 First attempts at international management

The first international conservation measures for tuna were implemented in the mid-1960s for yellowfin tuna in the eastern Pacific Ocean (EPO) by the IATTC (Joseph and Greenough, 1978). The prevailing policy at that time regarding fisheries for tunas was that access beyond 3 nautical miles of the coastline was open to the citizens of any nation who wished to fish. The resource was considered to be a common property of mankind, and to belong to whomever could first render it to his use. It was therefore "logical" that the form of conservation implemented by the IATTC was in the form of an output control, which entailed setting an overall quota on the catch. (A more detailed discussion of these programmes is presented in Section 3 below.) Any nation's vessels could fish under the quota, but once filled all would have to halt fishing for that species. This resulted in a race for the fish, and progressively shorter seasons as the fleet capacity grew. These facts caused increasingly greater confrontation among nations with large fleets capable of taking a large share of the catch before closure to unrestricted fishing (the "haves"), most of which were distant-water fishing nations (DWFNs), and nations with small fleets (the "have nots"), most of which were developing coastal states. The have-not coastal states maintained that a share of the resource should be allocated to them by virtue of the fact that the tunas spent time in waters under their jurisdictions, and that the newly developing Law of the Sea was recognizing an exclusive economic zone (EEZ) to 200 nautical miles seaward of their coastlines. The haves maintained that the tunas were a common resource, and belonged to whomever could catch them.

This disagreement between the two factions as to how tuna should be managed made it progressively more difficult for the states to agree on conservation controls. Without a limit on the number of vessels that could enter the fishery, the purse-seine fleet operating in the EPO increased five-fold between the onset of the controls in 1966 and 1979, while the catch of tunas only doubled. Competition continued to increase, and the catches per vessel decreased. Because of economic pressures on vessels in general, and because the perceived "rights" of the coastal states were not being met to the satisfaction of those states, the concerned states could no longer agree to conservation controls. This resulted in the large fleet fishing without restriction and overfishing of the yellowfin stock. This was a clear example of failure to resolve the differing views of open access versus rights-based management approaches resulting in unrestricted fleet growth and overfishing of a tuna stocks.

During the 1970s a similar situation was developing in the Atlantic Ocean: tuna fleets were growing and fishing effort was increasing. Bluefin in the western Atlantic was considered to be heavily overexploited, and in need of controls on catch and fishing effort. A significant portion of this increase in effort was the result of a spillover effect from the closures in the EPO. During the closure to unrestricted fishing in the EPO increasing numbers of vessels transferred operations to the Atlantic, where some of them concentrated effort off the eastern seaboard of the United States. Much of this effort targeted bluefin tuna. resulting in further overexploitation of the stock. In response to severe overfishing of bluefin, ICCAT set catch quotas and minimum size limits for that species in the western Atlantic. Meanwhile, in the eastern Atlantic and the Mediterranean Sea fishing effort was increasing, and bluefin in that region were being threatened with overexploitation. As fishing effort increased, bluefin was driven to below the AMSY level, and catch quotas were implemented. The increased fishing capacity resulted also in increased fishing mortality on yellowfin tuna in the eastern Atlantic. Competition for a limited supply of yellowfin resulted in increasingly greater catches of small fish. ICCAT instituted another output control in the form of minimum size limits for yellowfin tuna. This control proved to be ineffective, and the yellowfin stock continued to be subjected to excessive fishing pressure.

1.2.2 Changing philosophy of management

As the IATTC and ICCAT struggled to manage their fisheries, using output controls such as catch quotas and size limits, they came to realize that such measures alone were not effective in preventing overfishing. Using catch limitations alone without limiting the fishing capacity that could partake in the catch limit resulted in increased competition for a limited supply of fish, a classic case of a regulated open-access fishery that was first defined by Homans and Wilen (1997) and reviewed more recently by Gréboval and Munro (1999). As competition increased, earnings declined, resulting in pressure from the vessel owners to relax conservation controls. In the face of increasing vessel numbers and efforts by producers to circumvent regulations, the immediate reaction from the management authority would be to introduce additional controls. For example, in the EPO fishery there were limits on the catch of yellowfin tuna and small bigeye, limits on the amount of fishing for tunas in association with floating objects, limits on mortalities of dolphins in the fishery for tunas associated with dolphins, restrictions on types of gear and fishing practices, requirements to carry observers, requirements to contribute monetarily to the observer programme and a host of other regulations. In such a situation there can be so many regulations that fishermen can become confused as to which ones apply in every case; the tendency would be to circumvent them. Such micromanagement also raises the costs of harvesting.

It was clear to both the IATTC and ICCAT, and also to the more recently created IOTC and WCPFC, that such "micromanagement" of their fisheries would likely result in failure to sustain conservation programmes and failure to fulfill the objective of maintaining the stocks at AMSY levels. They recognized that there was too much fishing capacity operating in their fisheries and that for management to be effective some limits would have to be placed on fishing capacity. However, to successfully limit fishing capacity there would have to be some quantitative measure of capacity relative to the productivity of the resource and a move away from open-access/common-property concepts to rights-based management concepts.

1.3 Too much fishing capacity

At the 21st Session of the FAO Committee on Fisheries (COFI) held in Rome during 1995 it was concluded that the existence of too much fishing capacity was leading to overfishing, and was threatening the sustainability of the world's marine fish stocks. Governments and regional fisheries bodies were called upon to review the amount of fishing capacity within their jurisdictions and, where appropriate, to reduce the capacity of those fleets. In an effort to assist the governments and fisheries bodies in carrying out the COFI recommendation, FAO convened a meeting in 1998 (FAO, 1998) to study and recommend how to define, measure and control fishing capacity. A series of technical documents dealing with these issues resulted from the meeting, but no clear definition of fishing capacity was agreed to by the participants. A second meeting was called by FAO in 1999 (FAO, 2000) and charged with developing a simple and practical method for the measurement of fishing capacity. The definition of fishing capacity defined by this second FAO meeting, which is more of a reflection of economic theory than fisheries population dynamics, represents the maximum amount of fish that can be produced by a fully utilized fleet or vessel during a time period, given the size of the stock being fished and the level of fishing technology being employed. The vessel's fishing capacity represents some maximum level of fishing mortality that it can generate.

This FAO technical definition of fishing capacity has caused some confusion among fisheries scientists and fishing industry personnel as to how they view fishing capacity. In his discussion of the definition of capacity, Joseph (2005) noted that when fisheries scientists are attempting to define capacity they frequently use some input indicator such as a vessel's size or its engine power, as they believe them to be related to the ability of a vessel to generate fishing mortality. The fishing industry often uses size as a measure of capacity because it is related to how much fish a vessel can catch in a single trip. Economists mostly prefer some technological-economic approach, using potential output to measure fishing capacity, because such an approach can be used to compute optimal inputs (Morrison, 1985). The economists' approach is the one that is widely applied by governments throughout the world (largely administered through surveys of businesses) when measuring the amount of productive capacity that is utilized in different industries and in the economy at large (Corrado and Mattey, 1997), and is the approach taken by the FAO technical meeting.

The most common indicators of carrying capacity for high-seas tuna vessels used by fisheries scientists are: 1) gross registered tonnage (GRT), which is the total of all the enclosed space within a vessel, and is expressed in tons, each of which is equivalent to 100 cubic feet (ft^3). The GRT of a vessel can be easily changed by changing bulkheads and walls; 2) net registered tonnage (NRT), which is the total of all enclosed space within a vessel available for cargo, and is expressed in tons. The NRT can also be easily altered by changing partitions; and 3) fish-carrying capacity (FCC), which is how many tonnes of fish the vessel can carry when fully loaded. For most large tuna vessels there is a close linear relation between each of the measures, GRT, NRT and FCC. The FCC has been one of the most commonly-used measures of carrying capacity for purse-seine and pole-and-line vessels. It is easily understood by the fishing industry, and generally easy to compute. However, like GRT and NRT, FCC is a plastic measure that can change with the size of fish that are being loaded on board or the way the fish is packed for quality purposes (Gillett and Lewis, 2003). Because the measure is somewhat plastic, management agencies have had difficulties in fixing the exact value of FCC for individual vessels when regulations and/or monetary assessments have been based on that measure. To circumvent these problems, cubic metres (m^3) of refrigerated fish storage space, a less pliable measure of how much fish a vessel can carry, is being used more frequently as a measure of capacity.

Although fisheries scientists may have some difficulty in applying these technological-economic definitions of fishing capacity to their studies to estimate fishing effort and fishing mortality, the definitions facilitate studies to determine whether excess capacity exists. In fact, the two definitions, fishing capacity and carrying capacity, can be equivalent when a fleet of vessels is fully utilized, but for most tuna fisheries, carrying capacity for a fleet of vessels is probably most often less than fishing capacity.

Using the FAO definition of fishing capacity, and applying a linear programming technique, Data Envelopment Analysis (DEA), to estimate the technical efficiency and potential catching capacity of purse-seine fleets operating in different ocean areas, Reid *et al.* (2005), concluded that there was more fishing capacity available in all of the major purse-seine tuna fisheries of the world than was needed to take the current levels of catch. In short, there are too many purse-seine vessels currently fishing for tunas.

For their analysis of the EPO, Reid *et al.* (2005) used individual vessel data for the 1998-2002 period to estimate capacity utilization by vessel size classes. They concluded that excess capacity existed for all size classes and for all modes of fishing, and that excess capacity increased by more than 50 percent during the period of the study. For the Class-6 vessels (>363 tonnes of carrying capacity), which represent the preponderance of the fleet, the catch of yellowfin and bigeye combined could have been taken with about 66 percent of the actual fleet that made the catch, and for skipjack the figure was 71 percent. Given these figures the EPO purse-seine fleet could theoretically be reduced from the current level of about 185 thousand tonnes to 126 thousand tonnes of carrying capacity without sacrificing catch. (It is interesting to note that the scientific staff of the IATTC had previously advised the Commission that the optimum carrying capacity for the EPO fleet was approximately 130 thousand tonnes.)

In their analysis of the WCPO, Reid *et al.* (2005) concluded that excess fishing capacity existed for all major national fleets operating in the area, Japan, Papua New Guinea, the Philippines, the Republic of Korea, the Taiwan Province of China and the United States, and for the other fleets as a group. It was estimated that, on average, the purse-seine skipjack fishing capacity was between 14 and 35 percent greater than needed to take the available catch. For yellowfin and bigeye the capacity was between 11 and 28 percent greater than necessary.

In contrast to the EPO and WCPO analyses, individual vessel data were not available for the Indian and Atlantic Oceans. Therefore Reid *et al.* (2005) cautioned that because of the limited degrees of freedom and the paucity of the data with respect to detailed activities of the various nations and the modes of fishing, their estimates represented extreme lower-bound estimates of capacity. With these constraints, their analyses indicated that there is excess capacity in the Atlantic and Indian Ocean purse-seine fisheries for tuna. For the Indian Ocean capacity could be reduced by about 23 percent without reducing catch, while for the Atlantic the reduction could be about 13 percent.

From the foregoing review of the work of Reid *et al.* (2005) it appears that if all vessels operated efficiently the carrying capacity of the world's purse-seine fleet fishing for yellowfin, bigeye and skipjack tuna could be reduced significantly without corresponding reductions in catch. Unfortunately, similar analyses have not been undertaken for the other major fishing fleets: longline and pole-and-line vessels. Each of these types of gear harvests about 15 percent of the total take of tunas, and if effective management and conservation of the tuna resources is to be achieved, controls would have to be placed on these fleets as well.

Miyake (2005b) provides estimates of the size of the world's large-scale tuna longline fleet and the tuna resources available to it. He defines large-scale longliners as vessels greater than 200 GRT or overall lengths greater than 35 m, equipped with "superfreezers" capable of preserving fish saleable as *sashimi*-grade tuna. He reports that there are currently about 1600 large scale longliners operating on the world's oceans, and that they harvest about 400 thousand tonnes of tuna annually. This represents about 240 tonnes of catch per vessel, which Miyake estimates is the economic break-even point for these vessels. He also notes that it is unlikely that all of the large-scale longliners are currently fishing at their full capacities, due to economic, social and management restrictions, and that if all these restrictions were removed, their potential catches would be greater than 240 tonnes per vessel. In addition to the large-scale longliners, Miyake reports that there is a fleet of approximately 1400 small-scale longliners (vessels between 24 and 35 m in overall length) which harvest about 195 thousand tonnes of tuna annually. In addition to the large and small-scale longliners reported on by Miyake, there is a growing number of longline vessels of less than 24 m in overall length. These vessels, in many cases, are capable of fishing on the high seas and are equipped with superfreezers for *sashimi*-quality product, but, because their size, are excluded from monitoring activities by the some of the regional tuna bodies, so statistics on their numbers and catches are scarce. However, because they are a growing fleet they will have to be included in management programmes if the conservation objectives of those programmes to be achieved.

Even before the studies of Reid *et al* (2005), providing quantitative evidence of overcapacity in the tuna purse-seine fisheries, and Miyake (2005b) providing empirical evidence of overcapacity in the large-scale longline fisheries, the regional tuna bodies recognized that there was more capacity available in the fisheries under their jurisdiction than was needed to take the available harvest, and that this excess in capacity was making it difficult to initiate and maintain effective management programmes for their tuna fisheries. They all have come to realize that catch quotas, closed areas and seasons and minimum size limits alone are inadequate to the long-term needs of effective management and conservation, and that they must be coupled with limitations on fishing capacity. All of these bodies have begun studies of the problem of overcapacity, and some have initiated efforts to correct it. However, as already mentioned, there must be a change in the way nations view their responsibilities respecting the management of the highly-migratory tunas before the problem of overcapacity can be resolved: the rights of nations and individuals to fish on the high seas, the allocation of shares of the catch to nations and/or individuals, the rights and responsibilities of haves and have nots and of coastal states and DWFNs. The problems of too much fishing capacity can be resolved only if there is a willingness on the part of nations and individuals to make changes in how their rights and responsibilities on the high seas are perceived and exercised. The remainder of report will discuss these issues.

2. DEFINING THE PROBLEM

2.1 The tragedy of the commons

The technical fisheries and economics literature is replete with examples of the failure of management systems to adequately conserve the stocks of fish that they are charged with protecting. It has already been pointed out that about 25 percent of the stocks of marine fish are overexploited, and others are rapidly becoming so. The cause of these failures is mostly attributable to the way ocean fisheries have developed historically, particularly those exploited on the high seas, beyond the jurisdiction of coastal states. At first the resources of the sea were thought to be inexhaustible, and later they were considered to be a common property of mankind, with unrestricted access to them every individual's right. These concepts have led to overfishing. As long as a fishery is profitable, new vessels enter it, which eventually leads to overfishing and declining catches. However, the decline in catches often leads to higher prices, in which case the fishery continues to be profitable and attracts the entry of even more vessels. In addition, some vessel owners, in attempts to secure greater portions of the catch, may increase efficiency of their current vessels or construct more efficient vessels, which, of course, leads to even greater overfishing. Furthermore, when a fishery becomes unprofitable, government subsidies may be granted to fishermen so that they can continue to participate in what would otherwise be an unprofitable venture. Regretfully, this "tragedy of the commons" (Hardin, 1968) has been a popular replay in ocean fisheries. These experiences have led to the realization that the concept of common resource and open access need rethinking. The change that is underway in many fisheries is to move away from these concepts and to assign property rights in one form or another to the participants in a fishery. These rights have taken many forms, ranging from simple participatory rights that limit the number of fishermen or vessels that may participate in a fishery to the allocation and "ownership" of individual quotas that can be traded among participants.

2.2 Rights-based management

It is clear that some form of a use or property right is a fundamental prerequisite to the limitation of fishing capacity, *e.g.* in the simplest schemes, for which the number of vessels in a fishery is limited, but no other restrictions are imposed, the owners of the vessels included in the limit have a participatory right in the fishery, and those not included in that list are excluded from the fishery. There are other schemes for which use or property rights are better defined. These schemes generally consist of setting an overall quota on the allowable catch, and then allocating this quota among the participants in the fishery. In such schemes the incentive to race to catch fish is eliminated because each participant has a limit on the quantity of fish that he can harvest. In some schemes individual quotas are transferable (ITQ). These schemes would lead to the creation of a market for ITQs, which could, in turn, lead to a reduction in the number of vessels in the fishery: an efficient operator could buy a quota from a less efficient operator; the efficient operator could take the combined quota with the vessels that he already has, in which case the vessels of the inefficient operator would be removed from the fishery. As already mentioned, under a strictly open-access/common-resource philosophy it would not be possible to limit the number of vessels that can operate in a fishery. Any nation or individual would be able to enter the fishery and to participate within whatever conservation guidelines management might set. There have been some successful programmes in which property rights have been assigned that resulted in limiting the capacity of fleets to levels required for there to be effective management and conservation. In most cases these successes have been for national fisheries. Clark and Munro (2002) pointed out that the most difficult problem in any rights-based fisheries management system is determining how fishing rights should be defined and to whom they should be assigned. They noted that because of the controversy surrounding this problem governments, particularly democratic ones, have been slow to adopt rights-based limited-access systems in fisheries.

Fortunately for the tunas, with the exception of Atlantic and southern bluefin, and perhaps bigeye in some areas, the major stocks have not been overexploited, and governments are in a position to take effective management action to prevent severe overfishing. This would require moving away from concepts of open access and common property to the concept of rights-based management. This is difficult for tunas however, due to their wide distributions and highly-migratory nature and to the fact that many and diverse nations are involved in catching them or controlling access to waters in which they occur.

The 1982 LOSC and the UN Fish Stocks Agreement provide some guidance (and some confusion) on how this move from common property to rights-based management concepts can be considered. Article 64 of the LOSC defines the tunas as highly-migratory species, and calls on nations to cooperate in their management and conservation. Articles 56 and 61 recognize the rights of coastal states to control access to the waters under their jurisdictions, and therefore to decide who can fish for tunas in those waters, with the caveat (Article 62) that, if the resource is not fully utilized, access to fish must be provided to the vessels of other states. In the case of tunas however, nearly all species are fully utilized throughout their range, and therefore one might consider that the coastal state would not be bound by Article 62 to provide access. Confusing the issue is LOSC Article 116, which relates to the rights of states to exploit the resources of the high seas. Although Article 116 is qualified by Articles 117, 118 and 119, which refer to the obligations and responsibilities of states respecting the conservation and management of the resources, it is frequently interpreted to imply that a fishery cannot be closed to new entrants. This creates a fundamental problem in securing the cooperation of all concerned states in initiatives to limit access to tuna resources. The UN Fish Stocks Agreement provides a framework of support for the LOSC regarding tuna. Article 7 of the Agreement states the responsibility of coastal states and other states to cooperate to ensure conservation and optimum utilization of the tuna resources, and Article 24 addresses the issue of developing states and the responsibility of developed states to developing states regarding conservation of tuna stocks and the development of fisheries on them.

2.3 Achieving consensus

Reid *et al.* (2005) have shown that there is more purse-seine fishing capacity available than needed to take current levels of catch and any reasonable increases in potential catch, and that there is no room for additional fishing capacity in these fisheries without threatening the resources with overexploitation. Therefore, if fishing capacity is to be limited, the problem is to develop some means of enlisting the cooperation of all concerned nations in programmes to limit fishing capacity, *i.e.* fishing nations, non-fishing coastal nations and both coastal and non-coastal nations wishing to expand their tuna fleets. The problem is difficult to resolve because even the simplest form of restricting fishing capacity partitions the catch in some way. Currently, on a world basis, most of the tuna is taken by DWFNs, while the majority of the catch is taken inside the EEZs. In the Atlantic and Indian Oceans and the EPO nearly half of the catch of tuna is taken inside EEZs, while in the largest tuna fishery in the world, that of the

WCPO, more than 70 percent is taken inside the EEZs. Many of the coastal states do not have tuna fleets, or only small ones, but many of them are desirous of developing fleets. Therefore, they are reluctant to enter into any schemes to limit fishing capacity that would curtail their efforts to develop fleets. Before any schemes to limit capacity and allocate catch can become a reality there must be a consensus reached among the concerned players to do so. They must realize that the process of limiting capacity in itself is the process of assigning property rights, and that as soon as the numbers of vessels in a fishery are limited, the available catch is mostly allocated. The problems between the haves and the have-nots must be addressed and resolved before the matter of excess fishing capacity can be resolved and effective management becomes a reality.

There have been some initiatives undertaken by the regional tuna bodies to limit fishing capacity, but progress is slow. The most significant progress in developing a capacity limitation programme has been by the IATTC. In this case a list of vessels authorized to fish in the EPO is maintained by that organization. New vessels are not supposed to enter the fishery unless they are to replace vessels on the list. Vessels on the list are supposed to be transferable among the nations participating in the programme. Some capacity is held in reserve for coastal states without fleets, but desirous of developing them.

The remainder of this report will discuss the actions that have been taken by industry, governments and regional tuna bodies (including more detailed comments on the IATTC programme mentioned above) to manage tunas and limit fishing capacity, and some possible approaches that might be considered in the future.

3. TUNA FISHERY MANAGEMENT EXPERIENCES

Over the last half century there have been numerous efforts on the part of governments, regional tuna bodies and industry to manage tuna fisheries. Japan, during the 1950s, was the first nation to control the number of longline vessels fishing for tunas under its flag. The first international effort to manage a fishery for tunas was made by the IATTC in 1966, when it established a quota on the catch of yellowfin tuna in the EPO. Since these early efforts there has been a continuing series of initiatives in different regions of the world to manage tunas. Joseph (2005) reviewed these programmes through 2003; an updated version of this review is included below.

3.1 National approaches

Following World War II, the Japanese government directed considerable effort towards developing its fisheries, and by the latter part of 1960 Japanese longline vessels were fishing throughout the tropical and temperate regions of the oceans of the world. Longline tuna fishing was profitable, and the fleet grew. The increasing number of vessels and the growing labour costs began to erode the profitability of the fishery, so the Japanese government introduced programmes to limit the number of Japanese vessels that could operate in the fishery. By limiting the number of longline vessels, catch rates and economic returns were kept relatively high. However, because the tuna species targeted by the Japanese longline fleet are found throughout the oceans of the world, and because at that time they were considered a common resource available to whomever could catch them, the action taken by the Japanese government was not successful in halting fleet growth. To escape the limitations placed on them by their government, Japanese boat owners invested in the construction and operation of longline vessels in nations that had not placed controls on fleet growth. It was this flow of capital that stimulated the development of large fleets of longline vessels in the Taiwan Province of China and the Republic of Korea, and, more recently, the Peoples Republic of China and Indonesia.

Because the Japanese attempt to unilaterally resolve the problem of excess capacity was not successful, it was clear that any effective programme to limit fleet size and growth would have to be much broader based and involve all states with vessels participating in the fishery, rather than just Japan.

3.2 Regional intergovernmental approaches

3.2.1 The Inter-American Tropical Tuna Commission (IATTC)

As mentioned in Section 1.2.1, the first time an international high-seas tuna fishery had come under conservation controls was in 1966, when the IATTC adopted a catch quota limiting the harvest of yellowfin tuna in order to prevent the near-shore portion of the stock in the EPO from being overfished. At the time carrying capacity of the purse-seine fleet was about 40 thousand tonnes, and nearly all of it was under a single flag, that of the United States. The quota was structured in a manner that allowed catches to be taken on a "first-come, first-served" basis. The season for unrestricted yellowfin fishing commenced on January 1, and would be closed on a date that would assure that the quota would not be exceeded.

The conservation programme maintained high catch rates and profitability. This attracted new investment in vessels, and fishing capacity began to grow. As the fishing capacity grew, the length of the season of unrestricted fishing decreased from about 10 months to less than 4 months as more and more vessels raced to catch as much fish as they could before the season of unrestricted fishing was ended. Pressure to increase catch quotas beyond the recommendations of the scientists mounted. Most of the catch was still taken by vessels of the United States, and the coastal states of the region complained that the first-come, first-served basis of the conservation programme discriminated against them because they had fewer and smaller boats, and could not compete. This resulted in intense negotiations among the nations with interests in the fishery to allocate shares of the quota to the coastal states, small vessels, *etc.* (Bayliff, 2003: Table 4). In some cases the shares assigned to the coastal states were sufficient to allow their vessels to continue fishing throughout the year. This marked a significant change in the way management of tuna resources was viewed, and, in fact, was a small step towards rights-based management, even though the allocations were termed economic-need quotas rather than rights-based quotas.

During the mid and late 1970s most of the world had moved to or was moving towards an extended jurisdiction of 200 nautical miles. Because coastal states under this regime of extended jurisdiction controlled access to a significant share, if not a majority, of the world's tuna resources, their position regarding special recognition in sharing of the resources was strengthened. By 1978 the carrying capacity of the purse-seine fleet in the EPO had increased to about 170 thousand tonnes. As discussed in Section 1.2.1, pressure from all sides for increased catch limits and increased allocations was so great that agreement could not be reached to implement a catch quota, which resulted in overfishing the stock of yellowfin. As yellowfin abundance declined, much of the fleet left the EPO to fish in other ocean areas or remained in port because the catch rates were so low that vessels could not meet operating expenses. This situation continued, and fishing effort in the EPO remained low until the mid-1980s, by which time yellowfin abundance had increased to above levels corresponding to the AMSY, and vessels began to return to the fishery. In 1985 purse-seine carrying capacity was 115 thousand tonnes, and catch rates and profits were high. The size of the fleet was more or less in balance with the current levels of catch, and there was no need to place restrictions on the harvest. This situation attracted more vessels, and the fleet has continued to grow (IATTC, 1988).

Because of the rapid resurgence of the fleet and the fear that the earlier experience of overfishing would be repeated, the Commission began to consider the implementation of measures to limit the number of vessels entering the fishery, but such efforts were mostly unsuccessful. The purse-seine fleet continued to grow, and this larger fleet exerted increased fishing effort on yellowfin and bigeye tuna. To prevent overfishing, conservation controls were implemented for these two species. Until 1999 none of the conservation measures that were implemented resulted in limiting or halting the growth in the fleet. In fact, it seemed that the mere introduction of the idea of limiting fishing capacity stimulated fleet growth. Those states without fleets or with small fleets wanted to establish greater presences in the fishery before they were prevented from doing so by the introduction of capacity limitation measures.

After extensive international negotiation, the first measures to limit purse-seine fleet capacity in the EPO fishery were implemented in 1999. Purse-seine carrying capacity limits were assigned to each of the 13 nations involved in the fishery. (Not all of the 13 nations were members of the IATTC, but all participated in the negotiations to assign limits.)

During the negotiations several factors were taken into account in assigning vessel limits. The most important was the level of catches taken during 1985-1998 by vessels of each of the 13 nations. Other factors that were considered were catches taken within the EEZs of the nations bordering the EPO, the landings of tunas from the EPO in each of the 13 countries and the contributions of each of these nations to the conservation programmes of the IATTC. For countries that were participating in the fishery during 1985-1998, the allocations of fleet capacity were approximately equal to the capacities of the actual fleets operating during 1998. One coastal state that did not have a fleet, but which had a longstanding and significant interest in the tuna fishery of the EPO, was assigned a capacity limit that would allow that nation to acquire a tuna fleet. There were several other coastal states participating in the negotiations that did not have tuna fleets at the time, but they insisted that the agreement provide the opportunity for them to acquire fleets. A capacity limit for each of these coastal states to grow into was negotiated by the governments, thereby assuring that they could acquire vessels within the framework of the programme. The total limit set by the resolution for purse-seine vessels in the EPO for 1999 was 158 thousand tonnes of carrying capacity (including current carrying capacity operating in the fishery and carrying capacity for the coastal states to grow into). The scientific staff of the IATTC noted that a fleet carrying capacity of purse-seine vessels of about 130 thousand tonnes was adequate to harvest the current catches of tunas. The actual carrying capacity operating at the end of 1998 was 138 thousand tonnes. By the end of 1999 carrying capacity reached 158 thousand tonnes. It was clear that there was a rush to bring new capacity into the fishery before regulations prohibiting new entries could be enacted. Unfortunately, it was not possible for the nations to agree to extend the resolution in its original form beyond 1999. The result was continued fleet growth, and by the end of 2002 it had reached nearly 180 thousand tonnes.

With growing concern over the large increases in capacity, the IATTC intensified its efforts to limit fleet growth. The governments (1) agreed to established a definitive list of purse-seine vessels authorized by the participants to fish for tunas in the EPO (the Regional Vessel Register, RVR), (2) noted that any purse-seine vessels fishing for tunas in the EPO that are not on the RVR would be considered to be undermining IATTC management measures, (3) indicated that only vessels flying the flags of participating nations could be entered on the RVR, (4) instructed that carrying capacity would be measured as the volume of the fish wells, (5) prohibited the entry of vessels not included in the RVR to the purse-seine fleet operating in the EPO, except to replace vessels removed from the RVR, (6) made provisions for five coastal states bordering the EPO to add vessels to the RVR with a total combined carrying capacity not to exceed 20 thousand tonnes and (7) defined a participant as a member of the IATTC, and states, regional economic integration organizations and fishing entities that have applied for membership or that cooperate in the conservation programmes of the Commission.

The central principle encompassed in the RVR is that the capacity quotas are assigned to vessels, rather than to governments. The clear intent of this capacity limitation programme is to fix the number of vessels that are authorized to fish in the EPO at current levels, although the special provisions for certain coastal states would allow it to grow by about 17 thousand tonnes. It is also the intent of the programme to allow vessels in the RVR to transfer to any of the other 12 nations, thereby allowing the nation to which the vessels transfers to increase its capacity by the amount of the transferred vessel, but requiring the nation from which the vessel was transferred to reduce its capacity by that amount. If a vessel on the RVR is replaced, or its capacity is increased, then a vessel of equal capacity, or an amount of capacity equal to the increase in capacity, must be removed from the RVR. In a manner of speaking, the RVR creates a market for trading capacity. A vessel owner or a nation desirous of increasing its capacity can offer to purchase vessels listed on the RVR. When purchased, the vessel, which would remain on the RVR, along with its capacity quota, would go to the purchaser. Once the RVR was established through political negotiation, theoretically, any transfers of vessels among nations would result from market forces.

Since the inception of the RVR system there has been disagreement among some of the participants as to whether transferability was agreed to in the original resolution establishing the programme. Although this provision for transfer is not clear in the resolution, it was clarified in a document (IATTC, 2003b) presented by the Director of the IATTC: "The Secretariat's understanding of how the Resolution was intended to work with respect to transfers was to allow vessels on the Register to simply transfer flag from one participant to another. The participant the vessel was transferring from would not be able to replace the vessel, and there would be no restrictions on any participant being able to receive the transferring vessel."

Because of the confusion over whether there is transferability, as defined above, among the participants, several vessels were dropped from the RVR by their flag states. When they are dropped from the RVR by the flag state they are leaving the owners are informed that the vessels could not be authorized to fish by the flag they are transferring to unless that flag had unused capacity. Unless some arrangement by the participants was made to increase capacity the vessel would be declared to be participating in illegal, unregulated and unreported (IUU) fishing—there are vessels that have fallen into this situation. The participating governments agreed to increase the capacity limits for the states to which the vessels were transferring, and to allow the states from which they transferred to retain the capacity quotas for the departed vessels. This, of course, has resulted in the total capacity limits being increased and exacerbating an already serious overcapacity problem.

The IATTC has made a considerable progress in limiting fishing capacity in the EPO, but unless the issue of transferability is resolved along the lines it was intended to follow, the problems associated with too much fishing capacity will not be resolved.

3.2.2 The International Commission for the Conservation of Atlantic Tunas (ICCAT)

The first management measures implemented by ICCAT are discussed in Section 1.2.1. These included measures to protect small tunas and limits on the catches of bluefin tuna, but not limits on fishing capacity.

One of the first measures to limit the size of fishing fleets in the Atlantic was adopted in 1998 for northern albacore and bigeye. In that year the member governments of ICCAT agreed to limit the size of their fleets fishing for northern albacore to 1993-1995 levels and to limit the numbers of their vessels greater than 24 m in overall length fishing for bigeye tuna to 1991-1992 levels. It was also agreed that the limits on the number of vessels would be coupled with a limitation on GRT, so as to not increase total carrying capacity. Subsequently, a total allowable catch (TAC) of 34.5 thousand tonnes was set for northern albacore, which was allocated among the nations participating in the programme. For bigeye, additional recommendations were made, calling on the participants to limit their catches in 2004 to the levels of 2001. Specific limitations on the catches and numbers of vessels that could operate in the bigeye fishery were placed on several, but not all, nations with fleets fishing for bigeye in the Atlantic Ocean, *e.g.* the Peoples Republic of China was assigned a catch allocation of 5 thousand tonnes and a fleet limit of 60 vessels, the Taiwan Province of China 16.5 thousand tonnes and 125 vessels and the Philippines 2.1 thousand tonnes and 5 vessels. In order to have available information with which to monitor and ensure compliance with the resolutions, each participant was required to provide a list of vessels that operated under its flag in the northern albacore fishery in 1993-1995, and each year thereafter, and in the bigeye fishery in 1991-1992, and each year thereafter. In 2005, in response to the fact that the catches of bigeye by the Taiwan Province of China exceeded its assigned quota, ICCAT reduced its catch allocation to 4.6 thousand tonnes and the number of vessels that could target bigeye to 15.

These actions by ICCAT to address the problem of unsustainable exploitation of northern albacore and bigeye provide the basis for the nations participating in the fishery to manage these resources in an effective manner. By setting a TAC for each of these species, and allocating that TAC among the participants in the fishery, there is an opportunity for each nation to regulate the number of vessels authorized to fish under its country allocation. Unfortunately, hardly any of the participating nations with assigned country allocations have chosen to limit fleet capacity. The result is that fleets can continue to grow, and as they grow their owners will tend to apply pressure to their governments to negotiate for increasingly greater TACs and country allocations. Past experience has shown that this kind of behaviour results in the failure of conservation measures.

Although these initiatives are a step in the right direction, they fall short of their objectives. Because information to compare current fleet capacities with baseline fleet capacities has not been fully available, it is difficult to know if participating parties are indeed limiting their fleet sizes to recommended levels.

3.2.3 The Indian Ocean Tuna Commission (IOTC)

Although the IOTC has a much shorter history than the IATTC or ICCAT, it has undertaken several measures that have had an impact on the problem of fishing capacity. The earliest efforts were recognition by its members that fishing capacity in the Indian Ocean was probably in excess of what was needed to harvest the current catch, and that measures should be considered for limiting capacity. Accordingly, the Scientific Committee of IOTC was asked to make recommendations on the best estimate of the optimum capacity of the fishing fleet that would permit the sustainable exploitation of the tropical tunas. Due to a lack of information, however, the Committee was unable to make such recommendations.

In an effort to initiate the preliminary steps of limiting fishing capacity, in 2002 the IOTC approved measures to establish and maintain a Record of Authorized Vessels (RAV) of greater than 24 m in overall length authorized to fish in the Indian Ocean. Nations participating in the agreement could add or remove vessels to or from the RAV, so that the RAV itself does not limit the number of vessels authorized to fish. However, any vessel not on the RAV would be considered to be engaged in IUU fishing. Measures were also approved requesting that nations participating in the agreement undertake certain actions, such as closing ports to and prohibiting imports from vessels involved in IUU fishing and not granting the use of their flag to vessels that had been involved in IUU fishing unless the ownership of the vessel had changed. In 2005 the cooperating parties agreed that vessels of less than 24 m in overall length that fish in the Indian Ocean outside the EEZs must be on an IOTC list of vessels authorized to fish in the Indian Ocean, or they would be considered to be IUU vessels. The measures for vessels greater than 24 m in overall length, and for vessels less than 24 m in overall length that fish outside the EEZs, taken together would tend to reduce the number of vessels operating in the fishery because it would make it difficult or impossible for an IUU vessel to operate profitably in the Indian Ocean. However, the methods do not, in themselves, result in a reduction of vessels authorized to fish in the Indian Ocean.

In addition to the vessel lists, the IOTC in 2003 approved a resolution requiring each nation with more than 50 vessels on the RAV to limit the number of their fishing vessels greater than 24 m in overall length to the number registered on the RAV in 2003. Exceptions to this limitation are made for some nations with fleets under development. In approving this resolution, the Commission expressed concern that the measures taken result in some nations striving to bring their fleet capacities up to the 50-vessel guideline, resulting in an increase in capacity.

3.2.4 The Commission for the Conservation of Southern Bluefin Tuna (CCSBT)

The CCSBT is different from the other regional tuna bodies in that it is concerned primarily with southern bluefin tuna, and in that its area of concern is wherever this species is found. When the CCSBT was formed, its three members, Australia, Japan and New Zealand, were the only nations fishing for southern bluefin on a significant scale. A TAC of 12 thousand tonnes was implemented, and allocated among the three members. This provided the opportunity for the three nations to place controls on their vessels fishing for bluefin under the country allocations. In the case of Japan, certain restrictions were placed on the number of longline vessels that could participate in harvesting the allocation. Australia implemented a kind of ITQ system in which its share of the overall quota was partitioned among various Australian fishing companies, most of which were involved in aquaculture of bluefin. The companies control the number of vessels involved in harvesting Australia's share, and, because the industry seems to be limiting the number of vessels to reasonable levels, the Australian government has not considered it necessary to place overall limits on the number of vessels that can operate. Over the last few years, however, the number of nations fishing for southern bluefin has increased. The Republic of Korea and Indonesia have joined the CCSBT, and the five members share a TAC of 14 thousand tonnes. An additional quota of 900 tonnes has been set aside for non-member states fishing for southern bluefin tuna.

In an attempt to stem the growing fleet size and increasing fishing pressure on southern bluefin, and in keeping with the intent of the FAO International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU), the CCSBT has created a record of vessels greater than 24 m in overall length authorized to fish for southern bluefin tuna. The CCSBT considers any vessel that is not on the record and is fishing for southern bluefin to be engaged in IUU fishing. CCSBT members are urged to take certain actions against such IUU vessels in an attempt to correct the problem. The first action called for is to seek cooperation of the flag state of the IUU vessel in addressing the problem. If that approach fails, the members are urged to undertake more severe measures, including trade restrictions.

The impact of all these actions by CCSBT should serve to mitigate somewhat the problem of actual or potential excess capacity in the southern bluefin fishery, but, it is difficult to determine precisely how effective these measures are.

3.2.5 The western and central Pacific Ocean

The tuna fishery of the WCPO is the largest in the world, accounting for nearly 50 percent of the world catches of the principal market species, and the single largest purse-seine fishery is prosecuted there. Less than 20 percent of the catch in the WCPO is taken on the high seas, so the coastal and island states control access to most of the catch in the region. This potentially has a great impact on how management arrangements will be formulated. Nevertheless, the tunas are highly migratory, and the principles defined in Article 64 of the LOSC and the UN Fish Stocks Agreement apply with respect to cooperation among nations and management requirements that apply throughout the range of the species. In response to the mandates of these international instruments, the WCPFC was created by the nations with interest in the tuna resources of the region and entered into effect on June 19, 2004; its inaugural session was held in December 2004. The convention is responsive to the need for controlling fishing capacity when necessary. Article 5(a) of the convention notes that the WCPFC shall "take measures to prevent or eliminate ... excess fishing capacity", Article 10(g) states that the Commission shall develop "criteria for the allocation of the total allowable catch or the total level of fishing effort", and Article 10, 2(c) states that the Commission may adopt measures for "limitations of fishing capacity". During one of the planning sessions for the establishment of the WCPFC the governments represented at the meeting agreed that "all States and other entities concerned to exercise reasonable restraint in respect of any regional expansion of fishing effort and capacity". It is clear that the WCPFC provides the legal authority for the organization to deal with the problem of excess fishing capacity. Because of the newness of the WCPFC, it will have to build on what other institutions in the region, notably the Forum Fisheries Agency (FFA) and the Palau Arrangement, are doing and have done.

The oldest body with an interest in the tuna resources of the region is the Forum Fisheries Agency (FFA), which was created in 1979 by the 16 member countries of the South Pacific Forum to help them manage and develop their living marine resources, particularly the stocks of tuna inhabiting the WCPO. The FFA maintains a register of vessels that are eligible to apply for an access licence for fishing in the EEZs of FFA members. Any vessel that has been found to be IUU fishing with respect to the EEZ of any FFA member country is blacklisted, and cannot obtain an access agreement. This move has tended to reduce IUU fishing and associated excess capacity.

The Palau Arrangement for the WCPO purse-seine fishery, which was concluded in 1992, has the objective of limiting the level of purse-seine fishing in the region. The arrangement provides for an overall limit of 205 purse-seine vessels that will be licensed by the parties for fishing in their waters. Of the 16 FFA members, 8 are members of the Palau Arrangement. The majority of the catch of tuna from the area is taken in the waters of these eight members.

The countries that are members of the Palau Arrangement are in the process of examining a long-term management system based on national limits on the number of allowable purse-seine days fished. The Ocean Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC), along with the WCPFC and the FFA, will provide technical information and advice to the Palau Arrangement countries in order to assist them in developing the management system. The system being discussed would set a total number of allowable fishing days for the combined EEZs of the parties to the Palau Arrangement. It appears that this level of allowable effort will be set to ensure sustainable harvests of the stocks of tunas inhabiting the area. It also appears that the total allowable number of fishing days will be allocated among the coastal states that are party to the Palau Arrangement, and that these allocations will be made in proportion to the abundance of the resource in the respective EEZs and/or the levels of harvest made in those zones. Each country would then be able to license vessels to utilize the fishing days allocated to its EEZ. It is not contemplated that the number of vessels that can purchase licences to fish in the respective EEZs will be limited. However, the Palau Arrangement members have agreed to a combined limit of 205 vessels for all of the Palau Arrangement members. The licensing scheme being contemplated apparently will not include purse-seine vessels of the United States, which are licensed under a special arrangement with 16 of the Pacific Island nations. There are about 40 vessels in this arrangement. It should be kept in mind that the limit is expressed in numbers of vessels, rather than in carrying capacity. It is possible that a tendency towards more efficient vessels will develop, resulting in an increase in fishing capacity. As had been made abundantly clear by the scientists of OFP, the efficiency of fishing vessels can vary a great deal, so some means of standardizing the allowable number of fishing days to a particular class of effort will be necessary. It will also be necessary to monitor efficiency changes over time because of "capital stuffing," since once days are limited fishermen will try to compensate by increasing their efficiency by investment and adopting technological innovations. If the parties to the Palau Arrangement balance the number of vessels, taking into account fishing capacities of the vessels that they license, with the number of fishing days each of them has been allocated, this could serve to ameliorate any excess fishing capacity problems. However, there would have to be close cooperation among the countries in establishing this balance, as vessels may seek to purchase licences for more than a single EEZ, since tunas are highly migratory, and aren't always available in the same EEZs. The matter of subsidized vessels would also have to be considered in any system that might be developed if that system is to be most effective. A vessel with subsidies would be able to fish at lesser levels of catch and still make a profit, whereas an unsubsidized vessel would not. This would result in more vessels seeking licences than if there were no subsidies. Also, the area of the WCPO that lies beyond the EEZ of any nation will have to be considered in any scheme for controlling fishing effort and capacity. Once the WCPFC is fully operational, it will deal with the issue of controls in the high-seas area, but there will have to be coordination with what the coastal states are doing by way of licensing within their EEZs.

Although the effort limit scheme discussed above can potentially relieve the problem of too much capacity, it could be dealt with more directly and effectively if vessel limits were included in the allocations of total allowable fishing days. Also, in the WCPO, as in other areas, the problem of too many longline vessels must be dealt with, as those vessels take about 30 percent of the total catch of the region.

3.3 Industry arrangements

In response to decreasing catch rates in the world longline fishery and declining ex-vessel prices in the global purse-seine fishery, two industry organizations that deal with the issue of fishing capacity, one for large longline vessels and the other for purse-seine vessels, have been created over the last few years.

3.3.1 The world longline fleet and the Organization for the Promotion of Responsible Tuna Fishing (OPRT)

Two major factors have impacted the profitability of the longline industry. One is the high demand and high value placed on tunas for the *sashimi* market, which has caused longline fishing effort to increase more than the demand, resulting in declines in vessel profits. The other is the development of FADs, which increase the efficiency of capturing small tunas, including bigeye. Increased catches of small bigeye have reduced the recruitment of large bigeye to the longline fishery, resulting in reduced abundance and declining catches of these large fish, which are the primary target of the longline fishery. This situation has caused a great deal of concern for the longline industry. Because of this concern, and in keeping with the FAO International Plan of Action for the Management of Fishing Capacity (IPOA-CAPACITY), the Japanese longline industry has undertaken action to reduce the size of its large-scale, superfreezing, tuna longline fleet by approximately 20 percent. Because there are large longline fleets fishing under the flags of several other nations, the Japanese industry has undertaken measures to enlist the cooperation of many of those fleets in an overall programme to reduce fishing capacity of the world's longline fleet. Japan has targeted 130 vessels for removal from its fleet, and the Taiwan Province of China has agreed to limit its fleet to 600 vessels. The Taiwan Province of China will require that Taiwanese-owned vessels under flags of convenience be transferred to its registry. To stay within its 600-vessel limit, some of the recalled vessels will be "bought back" and scrapped, as will the 130 Japanese vessels. The Japanese government has prohibited the importation of tuna from vessels that might, by their actions, diminish the effectiveness of programmes to conserve and manage tuna resources, including efforts to control fishing capacity. The scheme has a chance to succeed because Japan is the primary market for *sashimi*-grade fish, and if that market were denied to a longline vessel, it would find it difficult to fish profitably.

The OPRT was originally established between an industry association that represents all Japanese high-seas longline vessels, and a similar association represents the Taiwanese longline fleet. Its objectives are to track tuna coming into the Japanese market to ensure that it is from cooperating nations, to monitor the removal and scrapping of vessels and to assist in the reimbursement of Japanese and Taiwanese fishermen for the costs of removing their vessels from the fleet. Longline fleets of Indonesia, the Republic of Korea, the Peoples Republic of China and the Philippines have joined OPRT. Some Japanese and Taiwanese longline vessels have been bought back by the Japanese and Taiwanese longline industries and scrapped. The buybacks were made by the Japanese and Taiwanese longline industries. Moneys were loaned to the industry groups by the Japanese government on a 20-year pay-back schedule.

This Japanese initiative to reduce the number of large-scale tuna longline vessels can be a useful means of controlling excess fishing capacity and contributing to better conservation of the tuna resources important to the longline fishery. However, to be effective, there are two other factors that must be considered. First, there must be effective measures to resolve the excess capacity problem in the surface fisheries, which, because of increasing catches of small bigeye, are having a serious impact on the abundance of large bigeye available to the longline fleets. Second, there are growing fleets of longline vessels less than 24 m in overall length that are not included in the vessel lists and management programmes of various organizations. Many of these vessels are registered in developing coastal states. These fleets of small vessels are fishing progressively greater distances from shore and taking increasingly greater quantities of tunas, and as the infrastructure in the coastal states processing and shipping *sashimi*-grade tuna to Japan develops, there will be an increasing need to include these fleets in any programmes to limit capacity in the world longline fleet. Until these problems are dealt with, there cannot be effective tuna management.

3.3.2 The World Tuna Purse Seine Organization (WTPO)

The number of large purse-seine vessels has been steadily increasing over the last several decades, and now comprises about 570 vessels with a total carrying capacity of nearly 600 thousand tonnes. Additionally, this growing fleet has increased its efficiency in catching tuna. This increase in productivity has been the result of many factors, including better vessel design, the use of sophisticated electronic equipment and the development of the use of FADs. With this tremendous potential to catch fish, when the supplies of tunas, particularly skipjack, are abundant, the catches increase sharply. These increases in production tend to outstrip demand and cause ex-vessel prices to decline. Conversely, during years when skipjack abundance is normal, or low, there is more purse-seine capacity than needed to take the available harvest. For most of the years since 1998 there have been abundant supplies of skipjack and catches in excess of demand, and prices have reached the lowest levels of the last several decades. This has caused serious economic problems in the purse-seine industry, and stimulated efforts on the part of purse-seine vessel owners to do something to bring supply into balance with demand. In 1999 several industry organizations representing purse-seine vessels came together to form an organization, the WTPO, to address this problem. The organization has attempted to treat the problem of overproduction by requiring vessels to spend more time in port between trips and by calling for a limit on fleet growth.

Although many vessels followed the recommendations of the organization regarding the length of time between trips, many others did not; so it is difficult to tell whether this has had an impact on prices. It has had little or no impact on excess capacity, because new purse-seine vessels continue to enter the fishery. Regarding limiting capacity, the organization has called for the establishment of a world purse-seine and longline vessel register, which would be open only to vessels authorized by their governments to fish. New vessels could enter the register only as replacements for vessels of an equal size removed from the register. So far, such a world register has not been implemented. The idea of an industry initiative to address the problems created by excess capacity in the world tuna fleet provides a number of possibilities, some which are discussed by Joseph (2003), for helping to resolve these problems.

4. MOVING FORWARD

There is almost universal agreement among governments, regional tuna bodies and industry that there is more than enough tuna fishing capacity to harvest the tunas, with the possible exception of skipjack, at the AMSY levels, and more than enough fishing capacity to satisfy the market demand for skipjack. Squires *et al.* (1998 and 2000) have pointed out that excess fishing capacity is wasteful, reduces economic rents, diminishes the economic viability of the industry and makes it difficult for regulators to reduce the total yields from a resource without imposing bankruptcies and job losses. There is also agreement among governments, regional tuna bodies and industry that limits should be placed on the numbers of vessels allowed to fish. It is also recognized that these situations of excess fishing capacity and overfishing exist because of the political framework within which tuna fisheries have developed. Specifically they have been considered a common resource to which there has been open access by the citizens of all nations. In some cases this approach has led to overfishing of some stocks, and, if continued, it will likely lead to overfishing of others. Efforts have been made to mitigate these threats of overfishing by imposing catch limits, minimum size limits and closed areas and seasons. These attempts have been only moderately successful because of the difficulty of enforcing them and because of the ever increasing pressures of a growing, competitive and economically-distressed fleet. In some cases the pressures have been so great that controls have not been implemented, and subsidies have been granted to vessel owners to mitigate severe economic hardship caused by excess capacity.

As discussed in earlier sections of this report, a solution to this problem would be to limit the numbers of vessels that are permitted to fish. Ideally, the limit might be the target fishing capacity, which can be considered as the maximum amount of fish that can be caught over a period of time by a fishing fleet that is fully utilized, while satisfying fishery management objectives designed to ensure sustainable fisheries. All of the major purse-seine fleets are well above this level (Reid *et al.*, 2005) and so are the fleets of medium and large longline vessels (Miyake (2005b). Before effective programmes to limit capacity can be implemented there are some issues that must be considered. These have been discussed in Section 1.3, and more extensively by Joseph (2005). Some of them are reiterated and expanded upon in the following paragraphs.

4.1 The need for change

Of fundamental importance is the need for a change in the way that the politics of resource use in the ocean have been viewed historically. So long as the concept of open access to a common resource prevails, overfishing, or the threat of overfishing, will continue. The vesting of some sort of property right to the participants in a fishery makes possible more flexible approaches to conservation of the resource. Fortunately, such changes have been underway during the last several years. These changes have been mostly in fisheries that lie solely within the jurisdictions of single nations, which is reasonable, since resolving ownership problems in such fisheries is much easier than in multinational fisheries. In many of its fisheries New Zealand has allocated shares of the resource to users, which has allowed the management system to limit fishing capacity and maintain sustainability in the fisheries (Dewees, 1989). Another example is that of the Alaskan groundfish fishery, one of the most important fisheries of the United States. In this fishery, rights to catch fish have been allocated to both groups and individuals, and as a result management has been able to control fishing capacity at levels commensurate with AMSY (Holland, 2000).

Pacific halibut (*Hippoglossus stenolepis*) provides an example of an international fishery for which property rights have been assigned to fishermen, which has led to the maintenance of both economic viability and keeping the stocks at AMSY levels. Vessels of two nations, Canada and the United States, harvest Pacific halibut. The International Pacific Halibut Commission (IPHC), of which the two nations are members, is responsible for the management of halibut. "The Commission began its management in 1924 with a 3-month winter closure. By 1932, it was evident that further action was needed and the first catch limit was set." (IPHC, 1998). Limits were set for each of the several areas that had been established, and vessels of Canada and United States vessels could fish in any of these areas. The season was opened to unrestricted fishing on January 1 of each year, and closed in each area when the quota for that area was reached. Under that scheme, competition for the available catch increased, fishing capacity increased, and the length of the open season decreased from a 9-month fishery to one that lasted only a few weeks. Eventually, during the 1970s, Canada and the United States established 200-mile EEZs, so Canadian vessels could fish only in the Canadian EEZ (which contained about 20 percent of the biomass of fish) and vessels of the United States could fish only in the United States EEZ (which contained about 80 percent of the biomass of fish). Canada limited entry into its halibut fishery in 1979, resulting in a relatively long season for a relatively small number of vessels, which eased transition to an individual vessel quota (IVQ) system in 1991. An open-access system continued for the United States vessels, resulting in excess fishing capacity and shorter and shorter seasons. Finally, in 1995, the United States adopted an individual fishing quota (IFQ) system. According to Squires *et al.* (2000), "Under open access, and prior to the transferable private production right or ITQ, production under the shortened production period—under the 'derby fishery'—required relatively large crew sizes, longer working days, and longer trips to catch as much halibut as possible. After the ITQ was introduced, the rivalrous consumption and competition over the resource stock found under open access was curtailed and the fishery could extend over a longer period. Consequently, both labor requirements and the duration of the working day or fishing trip declined. In short, full utilization of variable inputs under normal operating conditions depends upon the duration and intensity of operations. In turn, these are determined by institutions, customary practices, and social norms, and in the broadest sense, these factors differ according to the type of property right regime."

These examples of the assignment of use or property rights in both national and international fisheries provides clear evidence of their utility in avoiding "the tragedy of the commons" and implementing effective management and conservation measures, including limiting fishing capacity. The question is: is it likely that such a change in multinational tuna fisheries is possible? In Section 2.3 it was pointed out that it would be difficult to reach agreement among the divergent interests in the tuna fisheries of the world to assign property rights and limit the number of vessels that can operate and to achieve consensus as to how this would be done. In any scheme to limit capacity or allocate shares of the available harvest the "have-nots" will be reluctant to agree to anything that they perceive as limiting their opportunity to enter the fishery or to increase their participation in it. Furthermore, most of the world catches of tunas are taken in the EEZs of the have-nots, which they perceive as a strong reason for allocating greater shares of the catches to them. Therefore, since the tunas (with the exception of skipjack in most areas) are fully exploited, increased participation by the have-nots must come at the expense of the haves. These reductions in fishing capacity of the haves must either be great enough to provide the opportunity for have-nots to bring vessels into the fishery, or some mechanism for transferring vessels to them will be necessary. Additionally, criteria for determining how capacity would be assigned to the new entrants would have to be developed.

4.2 Making room with buybacks

Perhaps the simplest and quickest approach to take with respect to providing for the entry of have-nots into a limited fishery would be to set the initial capacity limitation level in excess of target or current capacity in the fishery and to use this excess to partition, according to certain agreed-to criteria, to have-not entrants. The next step would be to reduce overall capacity to the target level through attrition, or through some mechanism for buying vessels out of the fishery. If the former, the rate of attrition would likely be very low, and excess capacity would remain in the fishery for many years. If the latter, it would most likely be necessary for governments to be involved in financing the buybacks, since in this scheme catches would not have been allocated to individuals, and there would not be much incentive for industry to fund the buybacks.

An alternative approach would be for governments to buy back some vessels immediately after the capacity limits were implemented, and attempt to sell them to new have-not entrants. The rate at which vessels of the haves would be bought back would be determined by the rate at which have-not buyers could be found for them.

Based on the experiences in other fisheries, the assignment of transferable individual property rights in one form or another might be the most efficient and effective means of handling the problem of new entrants. Under such schemes a market would develop for shares of the potential harvest, thereby allowing any individual, group or nation to enter the fishery by buying a catch quota and/or a share of the total fishing capacity. Many of the have-not nations are developing coastal states and some consideration should be given to mechanisms for assisting them in the purchase of rights into the fishery in question if their cooperation in instituting effective management is to be assured.

4.3 Criteria for determining participation

The first allocations of catch in an international tuna fishery were made in the EPO in 1969 (Bayliff, 2001). At that time most of the catch was taken by United States-flag vessels. The coastal states had only a few small vessels, and contended they could not compete with the United States fleet during the season of unrestricted fishing. They therefore negotiated for special allocations, based on the fact that the tunas occurred in their coastal waters. At that time the United States did not recognize coastal states' jurisdiction over tunas. After extensive debate and negotiation, the criterion agreed upon to determine the allocations was based on "economic need". Vessels determined to be at an "economic disadvantage" relative to other vessels were provided special allocations that could be taken after the fishery to unrestricted fishing was closed. The allocations were assigned to all states, but specified for the economically-disadvantaged vessels within those state. The economically-disadvantaged vessels were generally the smaller purse seiners, pole-and-line vessels and vessels fishing under the flags of states with only a few purse-seine vessels. Allocations were progressively increased and applied to vessels of all sizes registered in developing coastal states (Bayliff, 2001: Table 4). During the 1970s many nations extended their jurisdiction over fisheries to 200 nautical miles. On the basis of this extended jurisdiction, the coastal states of the EPO negotiated to allocate the available catch in accordance with this criterion. The negotiations failed, and the fishery was unregulated from 1980 through 2003.

During the 1970s catch quotas were placed on bluefin tuna in the western Atlantic Ocean. The quota was allocated among the nations most involved in the fishery (Canada, Japan and the United States), no other criteria were considered. Countries, such as Cuba and Brazil, with very limited fisheries were exempt from the regulations. Since that time ICCAT has allocated catches of swordfish (*Xiphias gladius*), bigeye tuna and northern albacore among participating states. No firm criteria for making these allocations were defined; rather they were negotiated mostly on the basis of current levels of catches being taken by the nations. However, the member governments have held special meetings to develop criteria upon which allocations could be based, but so far there has been no agreement as to which criteria should be used.

Because of the heavily overfished state of southern bluefin tuna during the 1980s, Australia, Japan and New Zealand agreed to voluntarily restrict their catches of southern bluefin tuna to near their then current levels of harvest. When the Convention for the Conservation of Southern Bluefin Tuna entered into force these voluntary catch levels were formalized as allocated quotas.

More recently, the IATTC has allocated carrying capacities among the fishing nations. These allocations were made primarily on the basis of current levels of catch, but also considered historical catches taken within the EEZs of coastal states of the EPO, landings of tuna caught in the EPO at ports of each state and the contributions of the states to the IATTC.

In practice, allocations in international tuna fisheries have been mostly the result of intense negotiations among the involved parties, and, as seen above, have most often reflected the historic and current distributions of the catches. Many of the regional tuna bodies have recognized that there is an urgent need to develop a set of criteria that can be used as a basis for making allocations of catch and/or capacity and have established working groups and committees to identify such criteria. A working group of ICCAT has listed a series of criteria that can be considered for making allocations, and the Convention on the UN Fish Stocks Agreement [Article 10 (3)] lists 10 points to be considered in developing criteria for allocation. Joseph (2003) also provides a list of some of the most important criteria that might be considered in making allocations. Although identifying criteria to be used in allocating will never replace negotiations among countries, such criteria will ease the burden of intense negotiations, particularly if a weighting mechanism is developed for the use of the identified criteria.

4.4 Capacity growth

Another important problem that must be considered in any programme to limit fishing capacity is the effect of the limitations on the ability of the vessels remaining in the fishery to catch fish. There are many examples that show that when limits, such as closed seasons, restricted areas and restrictions on the types of gear that can be used are applied, fishermen are still able to increase the fishing mortality that their vessel are able to generate by increasing the efficiency of their operations. Such capital stuffing (Wilen 1985 and 1989) must be monitored and quantified, and the capacity limits must be adjusted to compensate for increases in fishing operations if management measures are to remain effective in conserving the resource.

4.5 Multi-species fisheries

The different tuna species frequently associate with each other in the same aggregations. Not only do these tunas aggregate together, but many other species associate in these aggregations. Most vessels capture more than one species of tuna during a single trip, and they frequently do that during a single set. They may also capture a variety of other non-tuna, non-target species. For example, longline vessels frequently catch billfishes and sharks, and purse-seine vessels frequently catch sharks, mahi-mahi (*Coryphaena* spp.), wahoo (*Acanthocybium solandri*) and rainbow runners (*Elagatis* *bipinnulatis*). The application of management measures may be complicated because a vessel directing its effort at one or two species may catch other species, including some that are or fully exploited or overexploited and others that are not fully exploited. In situations for which capacity limitations are being considered for a fishery directed at several species of tuna, including some that are over- or underexploited, the process of setting the levels of fleet size will be complicated. On one hand, if fishing capacity limits were established with skipjack, which is underfished, in mind, overfishing of fully-exploited yellowfin or further overexploitation bigeye could occur. On the other hand, if fishing capacity limits with bigeye, which is overfished, in mind, the catches of skipjack, which is underfished, would probably be reduced. Any schemes to limit fishing capacity must consider these characteristics of tuna fishing, and also the effects on the bycatch species, some of which are the objects of other fisheries.

5. THE ALTERNATIVES

Joseph (2005) presented a series of options to be considered for limiting fishing capacity. These options included input controls, such as licensing, limits on the numbers and sizes of vessels and effort restrictions, and also output controls such as quotas on allowable catches, including country quotas, individual quotas and transferable quotas. All of the options reflect a move away from open-access systems of management to rights-based systems. The simplest approach, the vessel register, does not provide a specific right to a quantity of fish, but provides a right of access to the resource. At the other end of the spectrum, quotas for specific quantities of fish are assigned to users, and the users can transfer those rights to other entities for some consideration. The options fall into two categories: 1) those that do not remove the incentive to increase capacity through increased efficiency, and 2) those that tend to remove that incentive. These are briefly reviewed below, and, when appropriate, expanded upon; however, the reader is referred to Joseph (2005) for a more detailed discussion of the various options. For the purposes of the discussion that follows, it is assumed, on the basis of the information presented in this report, that maintaining the *status quo* regarding the management of tunas is not a viable option, and that some means of limiting fishing capacity is necessary if the tunas are to be effectively managed.

5.1 Alternatives that do not remove the incentive for overcapacity

This category of measures seeks to limit the number and/or fishing capacity of vessels that are permitted to participate in a fishery. Because the quantity of fish each vessel may take is not limited, there remains an incentive on the part of vessel owners to take as large a portion of the total allowable catch as possible. Competition among the vessels remains high, and there is a strong incentive for each owner to improve the efficiency of his vessels so that they can take a greater portion of the total available catch. This capacity stuffing makes it more difficult to maintain conservation controls.

5.1.1 Vessel registers

The initiatives taken by the various regional tuna bodies to limit fishing capacity through the establishment of vessel registers are described in Section 3.2 of this report. On the one hand, two of the regional tuna bodies (ICCAT and the IOTC) maintain “positive lists” of vessels that are authorized to fish in the waters under their responsibility; vessels not on those lists would not be authorized to fish in the Atlantic or Indian Oceans. However, the lists do not limit the numbers of vessels that can be on them. New vessels can be entered on the lists if they meet the qualifications prescribed by the regional tuna bodies. On the other hand, the register of the IATTC limits the vessels that can fish in the EPO, and therefore limits the fishing capacity.

The approach taken by the IATTC is the only one that addresses the problem of overcapacity. Although, as discussed earlier, the IATTC model has several shortcomings that result in failure to control the expansion of fishing capacity as much as hoped, it nevertheless provides useful experience for development of more effective capacity limitation.

5.1.1.1 Regional registers

There is an Article 64-type regional tuna body in every area of the world in which commercial quantities of tuna are harvested. Each of these bodies has expressed a need to limit and/or reduce the capacities of vessels operating within waters under its jurisdiction. Some have made first-cut attempts at limiting capacity by establishing a register of vessels authorized to fish in their regions of competences. These attempts provide the basis for formulating a simple and straightforward model for limiting capacity—the Regional Vessel Register (RVR). The RVR discussed here would provide mechanisms for reducing excess capacity while allowing for the participation of have-not nations in the fishery. Because the implementation of an RVR would not address fully the overcapacity problem, so other controls on the fishery to prevent overexploitation would have to be established concurrently.

The first thing that the establishment of an RVR would do would be to place a moratorium on fleet growth. Each state would be required to provide to the regional tuna body a list of vessels that it had authorized to fish under its flag. To prevent a state from "padding" the list with inactive or non-functional vessels, or to prevent a flood of vessels from entering the fishery from other areas as soon as the intention to establish the register became public knowledge, only vessels considered to be actively fishing in the area could be listed on the RVR. An actively-fishing vessel might be defined as one that had been fishing in the area for at least 6 of the previous 18 months. To remain on the RVR, a vessel would have to remain active in accordance with the definition.

Purse-seine vessels come in all sizes, from small coastal vessels that can carry only a few tonnes of fish to the largest ocean-going vessels capable of holding more than 3 000 tonnes of frozen tuna. Most of the world catch of tuna by purse-seine vessels is taken by vessels with carrying capacities greater than 400 tonnes. The smallest purse seiners fish only seasonally for tunas, spending most of their time fishing for other species, *e.g.* anchovies, sardines, mackerels, *etc.* Some criteria would have to be established regarding which vessels could be included in RVRs. A useful criterion for listing a vessel on the RVR might be to include any purse-seine vessel with a carrying capacity greater than 25 tonnes for which the annual catch of the principal market species of tuna makes up more than 50 percent of its annual catch of all species combined.

In some fisheries tuna vessels may fish throughout the entire area of a regional organization, while in other areas fleets may be geographically isolated from other fleets. For example, in the western Pacific there are large fleets of vessels that confine their fishing to the area around the Philippines or Indonesia. It may therefore be necessary to consider the establishment of sub-regional registers to allow for these differences in the distributions of fleets. In such cases additional control measures, *e.g.* closed areas, would be needed.

The RVR, which would be maintained by the appropriate regional tuna body, would include information on each vessel, which would be provided and verified by the flag states. The information should *inter alia* include:

- Name of vessel
- Registration number
- Type of fishing method
- Previous names and previous flags
- Port of registry
- Registered owners, managers and/or operators
- Location and year of construction
- Length, beam and molded depth

- GRT and carrying capacity in tonnes
- Carrying capacity in cubic metres
- Number and power of main engine(s)

To ensure that it is adaptive to changing conditions in the fishery, a key feature of any RVR system would be allowance for transfer of vessels among users. This means that the capacity quota assigned to a vessel should remain with the vessel, rather than with the flag state. This has been one of the obstacles confronting the smooth functioning of the IATTC system. Although the intent of the IATTC system is that the capacity quota stays with the vessel, rather than the flag state, some states have removed vessels from the register when those vessels transferred to another flag. In cases when the receiving flag has no unused capacity, the transferred vessel, which would have been removed from the register by the state from which it was transferred, could not be entered on the register, and therefore would be declared IUU. The reasons why a state might chose to act this way are obvious. States with fleets would not want to lose those fleets to others, so they would keep a "captive" capacity quota to use later.

A market for vessel capacity would be created if the capacity quota followed the vessel to wherever it transferred to within the region. Without the transfer provision the value of a vessel would drop substantially, since it would be bound to a flag state, and that state could impose on the vessel whatever constraints or monetary requirements it chose. The vessel owner would have no options except to subscribe to the requirements, sell the vessel outside the region (although similar RVRs could be in effect in other regions), sell the vessel to someone within the same flag state, most likely at a reduced price, transferring it to some other use or abandoning or scrapping it. Maintaining transferability within the RVR system would also provide the opportunity for the have-nots to acquire vessels; they could compete in the market place for capacity allocations.

Another important feature that should be considered for an RVR programme would be the inclusion of measures to allow for vessel replacement. As vessels age, they must be replaced with new ones to ensure an economically viable and efficient fishery. However, the carrying capacity of the replacement vessel must not exceed that of the vessel being replaced, and that the replaced vessel must not be allowed to continue to fish for tunas in the area to which the RVR applied. It is likely that the replacement vessel would be more efficient than the one that was replaced; so some means of measuring the change in efficiency would have to be available, and mechanisms would have to be developed within the RVR system to adjust for these changes. In addition to changing efficiency, there is also the need to reduce fleet capacity in all of the fisheries because there is currently more capacity available than is needed to harvest all the species of tunas except skipjack at AMSY levels. At the outset, any RVR list instituted will provide for more capacity than needed for the fishery. An obvious means of achieving these reductions would be to remove vessels from the register, and the most commonly considered approaches would be through attrition or a buyback programme. Tuna vessels have a long operational life, so reduction of fleet capacity by attrition is not practical. This leaves buybacks as the only practical option.

Buyback schemes have been used in a number of fisheries; some have been government programmes and others industry programmes. Many have been successful, but there are several problems. These have been discussed by Holland, Gudmundsson and Gates (1999), Clark and Munro (2003) and Curtis and Squires (in press), and reviewed by Joseph (2005) with respect to tuna fisheries. Among the problems are ensuring that bought-back vessels do not reenter the fishery; the lack of motivation for the fishermen to sell back their vessels and replace them with more efficient ones and ensuring that most of buybacks are not the least efficient vessels.

When an RVR system is initiated there would be more vessels on the register than needed to harvest the tunas at the AMSY level. A buyback scheme could be used to reduce the fleet size to levels closer to the optimum. At the outset it is likely that government or international monetary funding would be needed to make the buybacks, due to the large capital expenditures that would have to be made, but once the fleet reached the optimum level the programme could be maintained by industry. For example, the current fleet limit for the EPO is for 243 vessels with a total carrying capacity of approximately 185 thousand tonnes. The target carrying capacity for the area is about 135 thousand tonnes. Since the modal vessel capacity is about 1 000 tonnes, the fleet should be reduced by approximately 50 vessels (or more if there was a disproportionate number of small vessels in the buyback group). At current vessel prices this represents a buyback valued at approximately 200-300 million US dollars. It would be unrealistic to think that the industry would be willing or able to make such payments at the outset of the programme. However, after the removal of 50 vessels through buybacks, the catch per vessel and corresponding profitability per vessel would increase and the industry would probably be a willing to fund further buybacks to compensate for increases in fishing capacity. Of course, a government programme to fund buybacks would be a subsidy to the fishery because it would increase the profitability of the vessels that were not bought back. However, such a subsidy might be considered acceptable, since it would mitigate problems of overfishing and place the industry in a position to fund its own programmes.

If each regional tuna body established an RVR along the lines outlined above there would be a global limit on purse-seine fishing capacity. However there would have to be some coordination among the regional tuna bodies to prevent problems, such as having the same vessel on more than one register, from arising.

5.1.1.2 A global register

If each of the regional tuna bodies establishes an RVR these bodies could work together to establish a global register. Such a list would be useful from several points of view. First, it would provide governments with a list of vessels that are authorized to fish for tunas in the world's oceans, and, by default, identify any vessels without such authorization, which would be deemed IUU vessels; second, it would prevent vessels from being carried on more than one register; third, it would facilitate legitimate transfers among regions; fourth it would facilitate monitoring and surveillance; and, fifth, it would be relatively easy to monitor changes in the capacity or characteristics of the world's purse-seine fleet.

The most logical place to assign responsibility for creating and maintaining the global register would be within the regional tuna bodies themselves. Responsibility could be delegated to a single regional tuna body by agreement of the other bodies, or they could be jointly responsible and work through a committee made up of representatives from each of the bodies. Alternatively, responsibility for maintaining the global register could be given to an organization outside of the regional tuna bodies, such as FAO or the World FishCenter.

5.1.1.3 Licensing

Possession of a licence would seem to be the same as being on an RVR, but there are things that could be done with a licensing scheme that could not easily be done with RVR schemes in their present form. Licensing schemes have been used in many fisheries to limit the numbers of vessels authorized to fish. Like an RVR scheme, licensing vessels to fish even if the numbers of licences are limited and other constraints such as catch quotas are implemented, does not take away the competition by the licence holders to catch fish. The tendency of fishermen to race to catch their shares (or, preferably, more than their shares) of the harvest and to improve the efficiency of their vessels will remain as long as the amount of fish each vessel can take is not fixed.

Notwithstanding this shortcoming, licensing has been used by several states to control entry into their fisheries (Sinclair, 1983; Wilen, 1988; Townsend, 1990), but has not been used by regional tuna bodies to control international tuna fisheries. Tuna fisheries are multinational, and developing a licensing scheme that is acceptable to all states involved in the fishery is complicated by issues of sovereignty. If each state in an international tuna fishery undertakes its own licensing scheme it would be difficult to create an effective programme for limiting capacity, but, if the authority to license was vested in the regional tuna bodies more versatile and effective systems could be developed.

A simple approach to limiting capacity through licensing would be for each state with vessels fishing in the region to license each vessel in its fishery and to issue new licences only for replacement purposes. If all states did this it would basically result in prevention of the entry of additional vessels into the fishery of the region. The results would be essentially equivalent to an RVR without a buyback provision. The same problems of excess capacity and making room for have-nots exist for this licensing approach as for the RVR approach. If transferability of licences was included in the programme have-nots could buy into the fishery; the marketplace would determine the value of a licence and any nation, group or individual would be able to compete in that marketplace for a licence.

Townsend (1992), Townsend and Pooley (1995) and Cunningham and Gréboval (2001) have discussed fractional licensing, and Joseph (2005) has suggested that it be considered for use in fisheries for tunas. Fractional licensing includes a reduction in fishing capacity at the outset of the programme, and could include transferability of licences.

If properly applied, the fractional licensing would eliminate the need for buybacks; its success would depend on the transferability of the fractional licences. The regional tuna body would determine the target size for the fleet, which for all fisheries would be less than the current fleet size. The total number of licences to be issued would be the fraction that the target fleet size is of the current fleet size. For example, if the current fleet size were 150 vessels, or 150 thousand tonnes of carrying capacity, and the target fleet size were set at 100 vessels, or 100 thousand tonnes of carrying capacity, each vessel would be issued two-thirds of a licence. A vessel would not be authorized to fish without a full licence, so the owner of one vessel who wishes to fish would have to acquire an additional one-third of a licence. Since the licences originally issued by the regional tuna body would be transferable, and since no vessel would be able to fish with less than a full licence, a market for fractional licences would develop. In reality, tuna vessels are not all alike; in general, the larger, newer, better-equipped ones have greater fishing capacities than the others. In the above example, some of the largest vessels might be issued licences with a "value" of 1 or more than 1, and the smallest ones might be granted licences with values of less than one half. This raises several problems. First, decisions as to the values of licences to be granted to each vessel would have to be made. This task would probably assigned to the regional tuna bodies, which would use the characteristics of the vessels and their catches per day of fishing during the previous few years to make their decisions. The problem of balancing capacities among buyers and sellers would be complicated, so some sort of brokerage house at which fractions of licences could be bought and sold would probably be needed. Because the conventions establishing the regional tuna bodies do not include provisions for the kinds of monetary transactions contemplated in a rational licensing scheme, they would have to be modified, or institutions would have to be created outside the framework of the organizations. If the proper number of licences were set at the initiation of the programme there would be no need for buybacks at that time. However, fishing capacity would probably increase due to improvements in equipment and fishing methods, so either some provision for buybacks would be needed to compensate for these efficiency changes, or the licences would have to be for a fixed term, at the end of which their values would be reduced to compensate for increases in efficiency. Since there would be a market for the licences, have-nots would be able to enter the fishery on the same basis as the haves.

A fractional licensing scheme has the advantage of equitability among the participants in a fishery. At the outset the value of each licence would be reduced by the same percentage for every vessel, and the cost of bringing a licence to unity would be proportionately the same for all vessels.

The owner of a vessel with less than a full licence for the area in which it has historically fished might wish to transfer that vessel to another area that does not have a fractional licensing scheme. This would not be possible, however, if the regional tuna bodies in the other areas have management schemes that prevent additions to fishing capacity in those areas (which they should have).

Joseph (2005) has suggested that auctions be used to sell predetermined numbers of fishing licences in order to manage tuna fleet capacity, but this approach has not yet been applied. An auction system could reduce fleet capacity and provide an opportunity for have-nots to enter a fishery. If the licences were issued for a limited term, the number of licences auctioned at the beginning of the next term could be reduced to compensate for increases in fishing efficiency during the previous term.

Ideally the regional tuna body would recommend a level of licensing less than the current fleet level, which would eliminate the overcapacity problem. Some of the vessels owned by unsuccessful bidders would be sold to successful bidders who did not own vessels and others would be converted to other uses or scrapped. Revenues from the auction could be used to compensate unsuccessful bidders whose boats were converted to other uses or scrapped. This would, in essence, be an industry-funded buyback programme. Have-nots would be able to enter the fishery by successfully bidding for licences.

Because of the many different sizes of purse-seine vessels, some system of setting the number of licences by size categories would have to be developed. This could be accomplished by setting the numbers of licences to be auctioned in proportion to the current size distribution of vessels, *i.e.* the numbers of licences in each size category would be a constant percentage of the numbers of vessels in each category in the current fleet.

There are several ways that an auction could be structured. One way would be for the regional tuna body to determine the numbers of licences to be auctioned, conduct the auctions, carry out the buybacks and monitor the overall programme. Another way would be for the regional tuna body to determine the numbers of licences, but delegate the conduct of the auctions and buybacks to an independent organization. Still another way would be for the regional tuna body to set the numbers of licences, but leave the auction and the buyback programme to the industry, as is done in the OPRT.

Like the other licensing schemes discussed here, this approach would need additional control mechanisms such as catch quotas to prevent overfishing; also it would not remove the incentive of fishermen to race to catch their share of the quota and to increase the efficiency of their vessels, but it would eliminate the need for government subsidies to fund buybacks.

5.2 Alternatives that tend to remove the incentive for overcapacity

For this category of management measures, the management system implements controls that tend to remove the incentive for vessel owners to increase fishing capacity by allocating the allowable catch among users or user groups.

5.2.1 Allocating the allowable catch

The assignment of catch quotas, as shares of the TAC, can result in a self-regulating mechanism to control capacity, particularly when the quotas are assigned to individual operators. In such cases the incentive to build excess capacity is virtually eliminated because the holder of a quota would have a good estimate of how much fish he could harvest, and would know how much capacity would be needed to take that harvest. (Actually, the holder might elect to have capacity somewhat in excess of the amount needed to harvest his quota, in case the quotas were increased due to increased abundance of fish or in case of permanent or temporary loss of one or more of his vessels.) If the quota were assigned to a nation, or to a group of vessels not all belonging to the same owner, there would be little or no incentive to limit fishing capacity, as the vessel owners could increase their shares of the overall catch by increasing the fishing capacities of their vessels.

Who gets what share of a limited resource has always been a problem for humankind, and has been the reason for major conflict among individuals, bands, tribes, nations and various other enclaves of people over the history of civilization; in some cases these differences have led to armed conflict. Disputes over fisheries resources have not escaped such conflicts. Some nations have been able to resolve problems of allocation within their national fisheries, but in multinational tuna fisheries that has been much more difficult to do. If governments are to reach agreement on allocation, each of them must believe that it is or will be better off as a result of allocation than it was before the allocation. For have-nots, this often means that they must perceive an opportunity to enter the fishery through direct allocation when they are ready, or to enter by buying someone out. There has been a great deal of attention paid in international tuna fisheries to defining criteria that can be used in assigning allocations. These have been discussed in Section 4.3 of this report and in more detail by Joseph (2003). Although long lists of possible criteria have been developed, most of the limited allocations that have been made in tuna fisheries have been based on short-term historical participation in the fishery in question and how much of the resource is caught or occurs in the EEZs of the nations participating, or wishing to participate, in the fishery. It appears from the limited experience and success so far in allocating tuna resources that a set of well-defined criteria for making allocations will be needed before management controls based on partitioning the catch among fishing interests can be implemented, particularly since many coastal and developing states have either entered or expressed interest in entering tuna fisheries. Among the many criteria that are being discussed, in addition to the two mentioned above, is a "genuine and/or legitimate interest" in the fishery in question. This concept has been written into a number of studies of allocation criteria and into international instruments dealing with fisheries, but a clear definition of what constitutes a genuine and/or legitimate interest is lacking.

In addition to the difficulties discussed above, the issue is complicated by the fact that the tuna fisheries employ several types of gear and several modes of fishing to catch several species of tunas. In the EPO, for example, purse-seine vessels fishing for tunas set their nets on tunas associated with floating objects (particularly FADs), on tunas associated with dolphins and on tunas in free-swimming schools. Yellowfin, skipjack, bigeye and a wide array of non-target species are often caught in a single set. Fortunately, the less abundant temperate albacore and bluefin tuna are seldom taken in mixed-species sets of purse-seine vessels. Matters are further complicated by the fact that the vessels of some nations tend to employ different types of sets, and may be geographically isolated from other fleets employing other set types. For example in the EPO fishery, Colombian, Mexican and Venezuelan vessels fish mostly for tunas associated with dolphins (almost all medium to large yellowfin), while Ecuadorian and Spanish vessels fish mostly on tunas associated with FADs (mostly skipjack, but with significant amounts of small to medium bigeye and yellowfin). Yellowfin and bigeye are fully exploited, and in need of limits on their catches, while skipjack can support increased fishing effort and catch. Formulation of regulations that would protect bigeye and yellowfin without severely reducing the catches of skipjack will probably require some sort of stratification of catch quotas by area, species and mode of fishing. Squires *et al.* (1998) have discussed the problems associated with the management of multi-species fisheries when individually-allocated quotas are used, which include complex species interactions, substantial mingling of stocks and limited ability of fishermen to target specific species. Accordingly, attempts to regulate tuna fisheries have met with limited success. Nevertheless, development of allocation schemes that can lead to resolution of the overcapacity problem in the world's purse-seine fisheries is possible.

Assigning allocations to nations has frequently been discussed. All nations with genuine and/or legitimate interests in a fishery would be included in the programme. Most or all of the principal market species of tuna could be included in the total allowable catches (TACs), or separate TACs could be established for each species, except probably for skipjack in most or all areas. In most tropical purse-seine fisheries TACs would be needed for yellowfin and bigeye because these species are fully exploited or over-exploited. If there were no TACs for skipjack, vessels would probably continue to fish for skipjack after the TACs for yellowfin and bigeye quotas were filled, and discard the yellowfin and bigeye at sea, which would, of course, result in exceeding the TACs for those two species. A solution to this might be to (1) set the quotas for yellowfin and bigeye at levels somewhat less than those corresponding to the AMSYs and (2) permit fishermen to fish for skipjack after the yellowfin and bigeye quotas were reached. However, they would be obliged to retain all of the yellowfin and skipjack that they caught, and the amounts of yellowfin and skipjack that they retained would have to be less than, say, 5 or 10 percent of the total landings for each trip of each vessel. Observers on the vessels would report any discards of yellowfin or bigeye. Vessels that exceeded the 5 or 10 percent limits would be penalized. An alternative would be to set a TAC for skipjack. If the TAC for skipjack were set on the basis of catch history of the three species in the fishery the discarding problem might be minimized, but would result in lost revenues from potential catches of skipjack, especially during years of above-average abundance of that species. Because of the problems associated with the stratification of the fishery that were mentioned above, the TAC for each of the species would have to be based on the catch histories of the nations participating in the fishery. The result might be a series of allocations to nations that were based on areas of fishing, species taken, and modes of fishing (set types). Using once again the example of the EPO fishery, Ecuador would require greater portions of the skipjack and bigeye TACs, while Mexico would require a greater portion of the yellowfin TAC.

In allocating to catches to nations, if there are no limits placed on the numbers of vessels that could participate in the fishery, there might be a tendency for capacity to increase, through either the addition of more vessels or increases in efficiency. This could be overcome in the nations that limited the fishing capacities of their fleets. However, the objectives of nations might differ; some might choose to maximize profits by limiting the number of vessels authorized to fish to the number that would be needed to take that nation's quota over the course of the fishing year, but others might choose to increase employment of fishermen and shipyard workers by having more vessels than necessary to harvest that nation's quota. If there were any nations in the latter category the problem of overcapacity would not be adequately resolved. Allocation of quotas to individual vessels might resolve this problem.

In the process of assigning individual quotas (IQs) the management system would be confronted with the problems of a multi-species and multi-modes of fishing described above for country allocations. In setting the overall TAC it would have to be determined whether it would include skipjack, or only fully-exploited yellowfin and overexploited bigeye. An overall catch limit including all three species might not work because fishermen might direct their effort mostly towards yellowfin and bigeye, for which they receive higher prices, which would result in overfishing of those two species. Furthermore, the abundances of the various species of tunas vary due to natural factors, as well as to fishing, so the TACS would have to be adjusted, probably on an annual basis, to best manage the fishery. One solution to this might be to set the quotas for the three species as percentages of the variable TAC. Once the TAC was selected it might be partitioned by areas and allocated to individual vessels or operators. There are two advantages to partitioning the quotas by area. First, fishing conditions vary from area to area. In the EPO, for example, yellowfin are caught in association with dolphins over a wide area of the EPO, but bigeye and skipjack, particularly the former are caught mostly between about 5°N and 5°S. Second, as stated previously, vessel of different nations fish in different areas and employ different modes of purse seining. All of the regional tuna bodies have adequate catch and effort statistics by area, season and mode of fishing to ensure that the assignment of IQs by areas would result in a total TAC for the region that would equal the overall TAC. The wide range of characteristics of purse-seine vessels operating in the fishery must be considered in setting the IQs. The statistical data bases could be used to determine how these assignments would be made. For example, personnel of the regional tuna bodies could determine how many vessels there were in each of several (say, six) categories and the annual average catches per vessel of each of the categories, and this information would be used as the basis for assignment of the allocations.

The major problems facing the assignment of IQs would be determining the basis for assigning them and the numbers that would be assigned. The simplest and most straightforward approach would be to assign an IQ to each purse-seine vessel in the fishery. As there is already overcapacity in all of the tuna purse-seine fisheries, this would not bring the fishing capacity to optimum levels, but it would at least prevent further increase in fishing capacity. An alternative approach would be for the management body to reduce the number of IQs to be allocated to less than the number of vessels in the fleet, increase the amounts of the IQs in proportion to the decrease in vessel numbers, and then auction the IQs to the highest bidders. The fleet size would be reduced to appropriate levels, and the unsuccessful bidders, whose vessels would be converted to other uses or scrapped, would be compensated from the proceeds of the auction. As was the case for some of the other systems discussed previously, have-nots could enter the fishery by bidding successfully for IQs. Finally, if IQs were properly set they would provide a self-regulating mechanism to control fishing capacity, as the vessel owners would have no reason to acquire more fishing capacity than necessary to harvest their quotas.

5.2.2 Transferability of quotas

Economists, *e.g.* Boyce (1992), Grafton (1996), Squires and Kirkley (1996), Squires *et al.* (1998), Clark and Munro (2002) and Hanneson (2004) have long advocated that allocated quotas should be a true property right and be transferable if the "tragedy of the commons" and overcapacity are to be avoided. They have argued that if the IQs were made transferable (ITQs), the more efficient vessel operators would tend to purchase them from the less efficient ones, and the fleet size would be reduced without a reduction in catch.

The ITQs would, in essence, be property rights that could be bought, sold or utilized. Before assigning the ITQs, the governments, working through the regional tuna bodies, would have to define the nature of the rights. Would the rights be held in perpetuity (Batstone and Sharp, 1999), or would they expire after a preset period of years? For many tuna vessels that are operated efficiently the loans for their purchase are paid off within a few years; so the duration of the ITQ might be set to expire when the loan for the vessel was paid, or at the end of the expected life of the vessel. After that period the ITQ could revert to the regional tuna body for sale to the same or other potential operators. Funds generated through such transactions could be used to offset the cost of management or to assist developing coastal states purchase IQs.

The establishment of ITQs would open several avenues for resolving some difficult issues in the management of tuna fisheries:

1) States that did not have tuna vessels, but would like to acquire them, would have opportunities to enter the fishery by purchasing ITQs.
2) Individuals or groups that are opposed to tuna fishing, that would like the catches of tunas reduced, or that would like the bycatches of endangered, threatened or icon species reduced by reducing the catches of target species, could purchase ITQs and retire them from the fishery.
3) The management agency would be able to purchase ITQs and retire them from the fishery in order to reduce capacity and increase average abundance of the resource.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

It is clear that the world's fleet of tuna purse-seine vessels has grown well beyond the level needed to harvest the principal market species of tunas, with the exception of skipjack, at levels corresponding to their AMSYs, and skipjack at levels necessary to meet the demand for that species. This overcapacity has caused severe economic problems in many of the tuna fisheries, and has made it difficult for the regional tuna bodies to implement effective measures to manage the tuna stocks, which has resulted in levels of exploitation exceeding those corresponding to maintenance of the stocks at AMSY levels. Most of the stocks of bluefin tuna are overexploited. All of the stocks of yellowfin are fully exploited, and cannot sustain increased levels of fishing mortality. It appears that bigeye tuna in the Atlantic and Pacific Oceans, and probably in the Indian Ocean as well, are being harvested at unsustainable levels. In addition to the overcapacity in the purse-seine fisheries, it is apparent that there is too much capacity in the longline fisheries as well. As a result, longline fishing is barely profitable (Miyake, 2005b).

The problem of overcapacity has become so severe in the tuna fisheries that the industry itself has taken measures to address the issue. The WTPO has called for a moratorium on the construction of tuna purse-seine vessels, and the Organization for Promotion of Responsible Tuna Fisheries has moved to reduce the number of large-scale longline vessels by 20 percent. Although these initiatives have fallen short of their objectives, they nevertheless demonstrate the seriousness of the overcapacity problems in tuna fisheries.

In efforts to correct the problem, all of the regional tuna bodies have initiated programmes to limit fishing capacities. In 1998 the IATTC began negotiations to limit the number of purse-seine vessels operating in the EPO to then current levels, and in each year since then has attempted to strengthen the programmes to limit capacity. The RVR developed by the IATTC is a move in the right direction, but it has not yet to resolved the problem. Between 1998 and 2006 the carrying capacity of the purse-seine fleet in the EPO has increased by about 35 percent. The problem of transferability of individual capacity quotas has not yet been fully resolved, is limiting the success of the programme. For example, when the owner of a vessel flying the flag of Nation A participating in the RVR programme sells that vessel to a buyer in Nation B that participates in the programme, Nation A has often retained that vessels quota, rather than transferring it to Nation B. If the vessel continued to fish, it would be classified as an IUU vessel. If Nation A replaced that vessel, it would add to the already excess capacity. The efforts of ICCAT to limit fishing capacity have been mostly in the form of recommendations to member and participating parties that they not increase their fleet capacities beyond certain designated levels. These designated levels were often chosen as those of the years with the greatest capacities and/or the greatest catches. The methods employed for monitoring changes in capacity have not been effective, and controls on fleet growth have met with limited success. The situation for the

IOTC is developing in a manner similar to that of ICCAT. In the WCPO, where the largest single purse-seine tuna fishery in the world takes place, an initiative to limit fishing effort, but not fleet size, is underway. It is still too early to know whether this programme will preventing overfishing, but it is certain that it does not directly address the problem of overcapacity, which represents a waste of capital that could be better directed at some other enterprise.

The construction of longline vessels that are less than 24 m in overall length, but capable of fishing on the high seas and superfreezing their catches so as to make them acceptable for the market for *sashimi*-grade fish is contributing to the overcapacity problem, as these vessels, unlike those more than 24 m in overall length, are not subject to limitations directed at reducing longline fishing capacity. This has resulted in an increase in the construction of these smaller longline vessel. Unless addressed, this situation can reduce the effectiveness of attempts to control longline fishing capacity.

It is generally agreed that the concept of open or unlimited access to tuna resources has led to too much fishing capacity, resulting in overfishing of some species and waste of capital. To resolve this tragedy of the common, nations must move away from this open-access practice and develop systems that assign use or property rights to the participants in international tuna fisheries. The assignment of these rights is a formidable task because of the difficulty in determining what the rights should entail, how they should be assigned and how those with a genuine and/or legitimate interests in the fishery, but not assigned property rights, should be treated. Several approaches to limiting fishing capacity in a fishery in which use or property rights have been assigned are presented in this report. Some of these approaches include incentives for limiting fishing capacity, and, as such, are self–regulating, while others do not include such incentives. The difference is whether the right provides an opportunity to fish, or whether it provides a limit on the quantity of fish that can be taken. In the former case, there would be a race to take as great a share of the catch as possible before the season ended, resulting in a tendency to increase the fishing capacity. In the latter case, a vessel owner would have no incentive to increase the fishing capacity of his vessel(s) beyond that necessary to harvest his quota. On one hand, the non-self regulating approaches include systems that provide authority or licences to fish through some sort of assignment or through competitive bidding. On the other hand, the self-regulating approaches allocate shares of the catch to nations, enterprises or individuals. The key to the success of either of these approaches is the inclusion of ITQs. An ITQ, when coupled with the allocation of catch quotas, would eliminate the incentive to increase capacity and would provide for the entry of have-nots into the fishery by allowing them to purchase ITQs. It would also provide the opportunity for groups that are opposed to fishing to purchase ITQs and set them aside in order to reduce fishery-induced mortality of target, bycatch and/or icon species.

Based on the information presented in this report, it appears that the most efficient means of controlling fishing capacity and managing the tuna resources of the world would be to institute a system of ITQs. This would bring fleet size into balance with the ability of the stocks, other than skipjack, to sustain current levels of catch, and into balance with the demand for skipjack. This would ensure that the fisheries were prosecuted on a sound economic basis, and would ease political tensions among nations operating vessels in the fishery. However, judging from the extended time it has taken for individual nations to develop licensing schemes with buyback provisions and/or ITQ systems of management, it would be optimistic to think that similar systems could be developed quickly for the complicated multi-national tuna fisheries. However, we are at a pivotal point in history of tuna fisheries. Most of the tuna stocks are in reasonably good health, sustaining high levels of catch. However, the available fishing capacity is far greater than that necessary to harvest the fish at levels corresponding to the AMSYs. This excess fishing capacity poses a threat to the sustainability of the tuna resource, represents a waste of capital, and decreases the economic returns to the fishery. Unless effective management measures are implemented in the near future, it is likely that the tuna stocks that are currently overfished will become further overfished and that those that are currently maintained at sustainable levels will become overfished. In addition, there will further waste of capital. Catch and effort restrictions will be inadequate to conserve these resources. We must act now to halt the growth in fleet capacity, and establish measures to reduce that capacity over the longer term. To achieve these goals, the following actions respecting purse-seine vessels might be considered:

First, all of the regional tuna bodies should agree to moratoria on the building of new purse-seine vessels for tuna fishing. The tuna industry itself has called for a moratorium, and governments should take advantage of this opportunity by following up the industry initiative. Implementing moratoria would provide the regional tuna bodies with time to develop more comprehensive programmes for capacity limitation and reduction.

Second, the development of RVRs within each regional tuna body, as outlined in Section 5.1.1, would provide a mechanism for limiting fishing capacity, and, if coupled with a buyback provision, could provide the opportunity for reducing fleet capacity to more optimal levels. It would also set into motion the application of rights-based management, making it easier in the long run to develop more efficient means of controlling capacity. Once the RVRs are developed for the regional tuna bodies, they could work together to develop a global RVR, which would provide a means of monitoring global fishing capacity and preventing spillovers from one fishery to another. The RVRs may not be the most efficient means of managing fishing capacity, but they may be the most practical means of accomplishing something over the short term, and once they have been implemented, there will be time to develop more efficient systems, without doing serious damage to the resources until those more efficient systems are established.

Third, once the RVR systems are in place, and capacity is under control, the regional tuna bodies would have time to examine the merits and possibilities for introducing more efficient rights-based systems, particularly ITQs, as outlined in Section 5.2. A well-designed ITQ system incorporates all of the attributes needed for efficient management: ITQ holders would utilize only enough fishing capacity to take their quotas, there would be no incentive for capacity growth, the fishery would operate on an efficient economic basis, opportunity for have-nots to enter the fishery would be available and environmental groups could purchase quotas to meet their objectives. However, because of the complexities in developing such systems, this will not happen soon, so it is imperative that the second option above be implemented as soon as possible.

Fourth, a strong enforcement capability will be required to eliminate IUU fishing and ensure compliance with the systems developed. The experience of ICCAT with bluefin tuna provides guidance on how this could be accomplished (Barrett, 2003). The regional tuna bodies should work together to develop mechanisms to persuade the owners of IUU vessels and the nations in which they are registered to comply with the conservation programmes. Such mechanisms could include the use of "diplomatic persuasion" by the members of the regional tuna bodies on the IUU nations, the use of "bad press" to convince the IUU nations that they should comply with the conservation programmes, denial of access to port facilities to IUU vessels or the use of trade and economic sanctions against the offending nations.

Fifth, purse-seine vessels take about 60 percent the world catches of tuna. The alternatives discussed above for limiting fishing capacity have been presented in the light of application to purse-seine fleets. If the issues of fishing capacity and effective conservation are to be resolved, controls must be applied to much of the remaining 40 percent of the world's tuna fleet. It has already been mentioned that the fishing capacity of the large-scale longline fleet should be reduced by about 20 percent. The industry has been attempting to address this problem, but its efforts have not been completely successful. Also, as mentioned above, the construction of longline vessels that are less than 24 m in overall length, but capable of fishing on the high seas and superfreezing their catches so as to make them acceptable for the market for *sashimi*-grade fish is contributing to the overcapacity. Pole-and-line vessels account for about 15 percent of the world catch of tunas. These vessels catch mostly skipjack, which are not overfished, but, in addition, they catch substantial portions of the world catches of albacore, and also yellowfin and bluefin. Relatively little research has been done on the pole-and-line fisheries for tunas. Nevertheless, rather than waiting for the results of such studies, the moratorium and RVR approaches suggested for purse-seine vessels should be applied to longline and pole-and-line vessels at the same time. In this way, 90 percent of the excess capacity problem would be addressed. The remaining 10 percent of the catch is taken in coastal waters by small vessels, using a variety of gear type (Gillett, 2005). It would probably be difficult to apply capacity controls to these small fleets that are similar to those applied to the large fleets. An alternative approach might to include special catch quotas that are assigned to these fleets and administered by the flag states. Regardless of how this is handled, it is imperative over the long run that controls be applied to all fleets, as otherwise efforts to control only large fleets would be placed in jeopardy.

Finally, at the beginning of 2007 an excellent opportunity will exist to initiate an action plan to control fishing capacity in the world's purse-seine fleet. In 1999 the Food and Agriculture Organization (FAO) of the United Nations approved an International Plan of Action for the Management of Fishing Capacity (IPOA-CAPACITY), which called on states and regional fisheries bodies to achieve efficient, equitable and transparent management of fishing capacity worldwide, preferably by 2003, but no later than 2005. More than five years have passed since the approval of this action plan. For tuna, with the exception of some limited success by the IATTC, little has been done to comply with the IPOA-CAPACITY. Purse-seine fleets have continued to grow, and, in the EPO, notwithstanding the fact that a programme to limit capacity has been in effect since 1998, carrying capacity increased by 35 percent between 1998 and 2006. This failure to implement the recommendations of the IPOA-CAPACITY agreement places in jeopardy the tuna resources of the world. An excellent opportunity to correct this situation will be at the forthcoming meeting of regional tuna bodies to be held in January 2007 in Kobe, Japan. At that time all of the executives and directors, plus key members of the plenary bodies of these organizations will meet to discuss a variety of issues related to the operation of these organizations. Since there is worldwide agreement that overcapacity exists in the tuna fisheries and that these excesses, unless corrected, are likely to result in overexploitation or further overexploitation of these valuable resources and in further overcapacity, priority should be given to outlining a plan of action to limit, and ultimately reduce, fishing capacity. Such a plan of action should include, as a first step, an agreement to set a moratorium on the entry of purse-seine and longline vessels into tuna fisheries, with implementation of the moratorium no later than January 2008. As a second step, the meeting should agree to implement a global RVR with transferability for purse-seine, longline and pole-and-line fleets, or an equivalent programme, within two years of implementation of the moratorium. Buyback programmes should be considered as part of this process. A third step would be to agree to undertake studies to examine the possibility of developing an ITQ system for tunas, including a provision for handling small coastal fisheries.

This outline of action may appear to be ambitious, and also presumptive on the part of the authors, but the world's tuna fisheries are on the cusp of a production curve, and unless states and regional tuna bodies exercise their responsibilities in a timely and effective manner our tuna fisheries and the resources upon which they are based will slide down the slippery slope of overfishing and further overcapitalization.

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Buybacks in fisheries

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ABSTRACT

Buybacks of fishing vessels, of licences or access and other use rights and of gear can be key management tools to address overcapacity, overexploitation of fish stocks and distributional issues. Buybacks can also contribute to a transition from an open-access fishery to a more rationalized one. As a strategic policy tool, buybacks can help restructure relations among participants in a fishery, creating positive incentives that reinforce conservation and management objectives. Buybacks, by reducing vessel numbers, increasing profitability, strengthening positive incentives, improving attitudes and lowering exploitation pressures on fish stocks, can also help in the establishment of self-enforcing voluntary agreements among industry participants. Selectively-targeted buybacks can also help conserve environmental public goods, such as the incidental bycatches of small tunas and species other than tunas when sets are made on fish associated with dolphins or with floating objects.

1. INTRODUCTION[1]

Buybacks of fishing vessels, of licences or access and other rights and of gear can be key management tools to address overcapacity, overexploitation of fish stocks and distributional issues.[2] Buybacks can also contribute to a transition from an open-access fishery to a more rationalized one. As a strategic policy tool, buybacks can help restructure relations among participants in a fishery, creating positive incentives that reinforce conservation and management objectives.[3] Buybacks, by reducing vessel numbers, increasing profitability, strengthening positive incentives, improving attitudes and lowering exploitation pressures on fish stocks can also help in the establishment of self-enforcing voluntary agreements among industry participants. Selectively targeted buybacks can also help conserve environmental public goods, such as the incidental bycatches of small tunas and of species other than tunas when sets are made on fish associated with dolphins or with floating objects.

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[1] This paper draws heavily from the papers in Curtis and Squires (in press), especially those of Groves and Squires (in press) and Hannesson (in press). It also draws from those of Joseph and Greenough (1978), Holland *et al.* (1999), FAO (1998, 2000), GAO (1999, 2000), Weninger and McConnell (2000), Joseph (2003, 2005), Joseph *et al.* (2007), Barrett *et al.* (2004) and World Bank (2004).

[2] Hannesson (2005) defines use rights to fish, either as rights to catch a certain quantity of fish (as a share in the total allowable catch, for example) or as rights to own and to operate a fishing boat for some specific purpose, depending on what method is found most appropriate for regulating the fish stock. To illustrate, Individual Transferable Quotas (ITQs) are a use right held by individual firms, but ownership—the property right—is retained by the state. This definition would encompass access rights, but a distinction is made in this paper between the general right to access a fishery and all of its potential species and use rights to harvest a specific quantity and/or specific group of species. Baland and Platteau (1996) provide further discussion on use and property rights.

Buyback programmes for vessels and licences have been widely applied in Europe, North America, Australia and Northeast and Southeast Asia. In Australia, they have been applied to the northern shrimp, Northern Territory barramundi, South East trawl, Western Australia rock lobster and Victoria Port Phillip bay scallop fisheries. In Northeast Asia, they have been applied to the Japanese high-seas longline fishery and to the Taiwanese offshore longline and drift net fisheries. In Southeast Asia, Malaysia bought back vessels in the west coast Peninsular demersal (finfish and prawn), pelagic and traditional inshore fisheries. In Canada, buybacks have been applied to the British Columbia Pacific salmon, Atlantic inshore lobster and Atlantic groundfish fisheries. In Mexico, buybacks have been applied to the Gulf of California shrimp trawl fishery. In the United States, buybacks have been applied to the New England groundfish trawl, Pacific Northwest salmon troll (licences), Pacific coast groundfish, Texas bay and bait shrimp (licences), Bering Sea groundfish, Alaska snow crab and Gulf of Mexico longline fisheries. The European Union Multi-Annual Guidance Reduction Program has applied buybacks in Denmark, Italy, France, the Netherlands, Spain, Sweden and the United Kingdom. In Norway, buybacks have been implemented for purse-seine and trawl fisheries and traditional fisheries with smaller vessels, including nets, longlines or hand lines. Gear buybacks are less frequently employed than licence and vessel buybacks. The 1994 Florida Net Ban on entangling nets (gillnets and trammel nets) is one of the few documented cases.

2. BUYBACKS TO ADDRESS OVERCAPACITY AND OVERFISHING

The problem of overcapacity in tuna fisheries has become a serious issue. The World Tuna Purse Seine Owners Association (WTPO) called for a moratorium on the construction of tuna purse seine vessels. The Organization for the Promotion of Responsible Tuna Fisheries (OPRT) has moved to reduce the number of large-scale longline vessels by 20 percent. Reid *et al.* (2005) showed that there is more fishing capacity available in tuna purse-seine fisheries than is necessary for current harvest levels. They further demonstrated that additional fishing capacity in these fisheries could threaten the tuna stocks with overexploitation.

Joseph *et al.* (2007) observe that most of the tuna currently harvested on a world basis is taken by distant-water fishing nations, with a majority caught within the Exclusive Economic Zones (EEZs) of the states adjacent to the resources. In the Atlantic and Indian Oceans and the eastern Pacific Ocean (EPO), nearly half of the catch is taken inside the EEZs, and in the western and central Pacific Ocean (WCPO), more than 70

Economic incentives can be either positive—"carrots"—or negative—"sticks" (Barrett 2003). Positive incentives are created, for example, through enhanced property rights, where profitability increases, or vessel buyback programs, where profits can increase for the remaining vessels and payments are received for selling a vessel when exiting the fishery. Negative incentives, such as the trade sanctions or loss of market access enacted by the North Pacific Fur Seal Treaty or Japan for the Organization for Promotion of Responsible Tuna Fisheries, are more disruptive and difficult to implement, although in many instances, necessary. Credibility is more likely to come from stiff punishments, but such punishments can hurt cooperating fishers or countries as well, and hence be more difficult to achieve credibility or to implement.

per cent of the catch is taken inside the EEZs. Many of the coastal states do not have tuna fleets, or only small ones, but nonetheless would like to develop their fishing capacities. Programmes to limit and even reduce fishing capacity, such as buybacks, will have to directly address the desires and rights of these coastal states to develop their fishing capacity, while also addressing the current level of fishing capacity.

Vessel, licence or access rights, or gear buybacks, are one of the key policy instruments to address excess fishing capacity, overexploitation of fish stocks and distributional issues, and are one of the few alternatives to a property-rights approach to address these issues. By directly reducing fishing capacity through removing vessels and licences and relieving pressures on resource stocks, vessel profits and resource rents can potentially rebound, fish stocks can recover and income and wealth distribution can change through redistribution of access and compensation and transfer payments. The objectives of most buyback programmes often include a mixture of all goals, and simultaneous pursuit of these objectives is possible, and not necessarily contradictory. Buyback programmes often arise in response to a crisis, implicitly acknowledging that long-term profitability and resource conservation objectives may not be met without drastic action by the time these programmes are introduced.

Buybacks can directly bring fishing capacity closer into balance with the ability of stocks of tunas to sustain target levels of catch and to generate sustainable rents in the fishery.

One of the more common intentions of vessel buyback programmes centers on conserving or, more typically, rebuilding overexploited fish stocks. Nursery grounds may also be protected through buybacks. All of the European Union's Multi-Annual Guidance Programmes (EU MAGPs) included rebuilding overexploited fish stocks as one of intentions of the programmes, as did the buyback for the Taiwanese offshore fishery. In contrast, the Australian South East trawl fishery buyback's goal did not include protection of overexploited resource stocks, because the fishery was already managed by Individual Transferable Quotas (ITQs), and the corresponding Total Allowable Catches (TACs) were not fully utilized.

A successful buyback can raise profits received by owners of vessels and licences and economic rent to the fishery in the short run. Fewer vessels means that rent is shared among these fewer vessels. Lesser fishing capacity can lead to greater catch rates for the remaining vessels, possibly allow gains in economies of scale and scope for the remaining vessels and reduce overall industry costs (especially capital) and vessel costs.[4] Rents to crew members are also shared among fewer vessels. To the extent that the volume or timing of landings is not substantially altered, fish processors are likely to be unaffected in the short run.

Buybacks in fisheries do not, by themselves, necessarily sustain profits to vessels and rents to the fisheries over the long run. Long-run rent gains depend on the ability to limit replacing, or even expanding, fishing capital. Economic welfare can fall with additional investment in the post-buyback fishery if the use or property right conditions underlying the "Tragedy of the Commons" (Harden 1968) are not ameliorated, so that further investments are redundant from the perspective of society.[5] In the absence of property rights or taxes, increased resource rent can reinforce the very investment incentives that lead to the initial overcapacity.

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[4] Economies of scale are reductions in unit harvesting costs when costs, especially fixed costs, are spread out among greater levels of output or catch. Economies of scope are cost savings from joint production of multiple outputs or species.

[5] Continued technical change can increase rent in the short run, but countervailing pressures can be created that lower rents over longer time periods to the extent that resource stocks are adversely impacted (Squires 1992). Campbell (1989) observed that the net benefits of a buyback vary positively with the share of the restricted input(s) as a proportion of total costs and inversely with the ability to substitute between restricted and unrestricted inputs. Clark, Munro and Sumaila (2005) suggested that to the extent buybacks come to be anticipated by fishers, fishers will be motivated to acquire vessels, even if the prospects of making a normal return on their investments are low. As a result, to the extent that fishers anticipate future benefits, there can be greater overcapacity than would otherwise occur.

Buybacks in transnational fisheries exploiting highly-migratory species face the additional complexity of jurisdictional issues, different flag states, national sovereignty, coastal and distant-water nations, highly-migratory and transnational fish, vessel mobility across EEZs and the high seas and the different methods of fishing (fishing on tunas associated with dolphins, associated with floating objects or in free-swimming schools), some with incidental takes. Unilateral buybacks of vessels by individual flag states may achieve little or no conservation, because vessels from other countries may continue to exploit the same resource stocks, *i.e.* they may free-ride on the efforts of participating parties. This issue, for example, limited any resource stock improvements from buyback programme for the Italian drift gillnet fishery for swordfish (Spagnolo and Sabatella in press). Buybacks in multinational transboundary fisheries instead require a cooperative, multilateral approach, such as the buyback of high-seas tuna longline vessels conducted by Japan and OPRT.

3. BUYBACKS AS A TRANSITIONAL STRATEGY

Buybacks may form part of a transitional strategy to a more rationalized fishery—one that is more closely integrated into the rest of the economy. As long as management is based on input controls or total allowable catches (TACs) and without strengthened property rights, buybacks may not be the long-term answer, since vessels can expand fishing capacity by increasing investments and use of uncontrolled inputs (Wilen 1979, 1988, Townsend 1992) and technical progress (Squires 1992). Moreover, when fisheries are mired in debt and an absence of vessel profits and resource rent, cooperation is difficult to achieve among fishers. Under adverse conditions, individual discount rates can be exceptionally high as vessel owners scramble to cover vessel mortgage payments and even cover operating costs, excluding maintenance. As a transitional strategy, however, buybacks can help counter these adverse forces, and in transnational fisheries harvesting highly-migratory species multilateral buybacks may have a unique role to play due to limits in international law and property rights.

After a successful buyback, when a fishery resumes profitability, increased cooperation can follow. The smaller number of fishers also contributes to increased cooperation, and the remaining fishers tend to be those most committed to the long-term economic viability of the fishery. An industry-initiated and financed buyback of vessels in the Pacific coast groundfish trawl fishery of the United States improved attitudes and incentives and helped lay the foundation for a planned programme of ITQs. Buybacks of vessels in the Australian South East Trawl Fishery were intended to reduce the perceived overcapacity in the fishery and settle some distributional issues, thereby allowing a quicker transition to optimal catch levels (TACs were not binding for the ITQ-managed species).

Autonomous adjustment following a management change may be relatively slow. A key factor influencing the rate of change is the alternative uses for retired capital. If there is not another fishery in which a vessel can be used, it may be rational for an operator to delay exiting the fishery until the vessel is at or near the end of its economic life (Newby, Gooday and Elliston, 2004). Buybacks can help speed the transition under these circumstances, as in the Australian northern prawn fishery.

4. FEATURES OF BUYBACK PROGRAMMES

This section examines some of the most important features of buyback programmes based on the global experience. Papers in Curtis and Squires (in press) more extensively discuss these and additional components of buyback programmes.

4.1. Critical preconditions

There are several critical preconditions for a buyback of licences or vessels. One of the first steps starts with proper registration of licences and vessels to create a well-defined group of eligible owners and to provide well-defined boundaries to the fishery and the programme. Because of the prevalence of eligibility requirements and different buyback pricing formulae, the registration typically includes some combination of measures of the heterogeneous capital stock, such as vessel size (gross registered tonnage (GRT), gross tonnage (GT), length, fish-carrying capacity) and/or engine power (horsepower or kilowatts), plus catch history, revenue, home port, gear type, methods of fishing, vessel age, crew size, area fished and so forth. The EU register of fishing vessels was not yet established prior to the first two EU MAGP programmes, and there were disparate units of fishing capacity (vessel tonnage and kilowatts), which hindered monitoring. In some instances, a time series of some of these measures, such as catch history, is required for each vessel, such as when a window of multiple years is used to establish eligibility. For example, the vessel buyback programme in the Taiwanese offshore fishery over 1991-1995 purchased only vessels more than 12 years old (Sun in press).

A second critical precondition of buybacks is *in situ* measures to prevent new vessels from entering the fishery in place of the ones that have been removed. Without a pre-existing programme of limited entry, ITQs or some form of common or private property or use rights that strengthen the exclusive-use characteristic of property rights, funds from purchased vessels or licences can be used to purchase an upgraded or new vessel for the fishery, or new participants may enter the fishery as it becomes profitable. In the Italian Adriatic trawl buyback, the Italian government introduced a moratorium on new licences and a limit on construction of new vessels, whereby building a new trawler was allowed only if a larger vessel, not less than 120 percent of the new one, was scrapped. The latter reduced the average GRT per vessel, but had less effect on kilowatts per vessel, since the regulation was limited to GRT and not kilowatts.

A related issue is funds received from the buyback used to finance further investment in existing vessels held by the same owner, or to reenter the fishery by selling a vessel or licence and using the proceeds to purchase an existing vessel or licence. If there are permit holders that are not actively fishing, but eligible to enter the fishery, one of these permits could be purchased for far less than the funds received to exit the fishery, and fishing effort could potentially expand. Public funding of buybacks can exacerbate this problem of fishing capacity expansions through investment and technical progress for the remaining vessels, since additional funds from outside of the sector are now potentially available for owners of exiting vessels, permits or gear. The New England groundfish buyback programme was adversely affected by sellers reentering the fishery by purchasing previously inactive licences.

4.2. Who pays for buybacks?

Buyback schemes have been funded largely by central governments. The World Bank (2004) observes that public funding may be appropriate initially in terms of correcting past policy errors, and that buyback schemes are effectively government subsidies for the improved performance of the fishing industry. The MAGP has been largely funded by the EU, although various member states of the EU have financed portions of the buybacks. For example, EU funding in France was supplemented by the French government and local communities (regions and departments). Public funding of the Australian South East trawl buyback, for example, was deemed necessary to help redress problems with the initial ITQ allocation and the need to encourage and stimulate ITQ trades through a more rapid period of structural adjustment. General public revenue funded the British Columbia salmon buyback programme, although revenues from vessel sales helped raise funds.

Mixtures of funding have been used. Commercial and recreational fishing interests may finance all or part of the buyback, usually in conjunction with public funds. Financing includes government grants, annual payments from licence fees and commercial or government loans. Industry financed 80 percent of the Australian northern prawn buyback programme through commercial loans serviced by levies on remaining fishers (World Bank 2004). The United States Pacific coast trawl vessel buyback programme was funded by a federal government loan that is to be paid back by fees on the landings of the remaining vessels. The Australian Northern Territories barramundi fishery buyback was financed by commercial loans against expectations of future licence revenues (World Bank 2004). During the early 1980s, fishing vessels remaining in the Japanese longline tuna fleet paid compensation to the owners of the 169 vessels withdrawn (Kuronuma 1997). Eighty percent of the compensation was from government loans to the remaining vessel owners, and the other 20 percent was paid by private funds. In the Texas bay and bait shrimp buyback programme, the cost is borne partially by the shrimp fishery through a surcharge on licences, partially by society through public funds (including federal funds) and partially by the recreational fishery through the increased fee for the salt water fishing stamp.

A commercial fishery-financed buyback finances the programme from the proceeds that are expected to arise following the expected recovery. Such a buyback can be funded initially by a public loan, which is paid back by the commercial fishery, based on landings fees. In this case, the public bears a substantial portion of the risk of the loan. Non-governmental organizations (NGOs) can finance these programmes through purchases of licences or vessels. The World Bank, Asian Development Bank, Inter-American Development Bank and other such organizations may have an important role providing initial funding for industry-financed buybacks in transnational fisheries.

When a buyback is financed by commercial or recreational fishers, the buyback's debt obligation then becomes collective, rather than individual. Collective borrowing, rather than borrowing by individuals, also spreads the risk among the remaining fishers.

Responsibility for payment can, in principle, be assessed by evaluating the recipients of the buyback benefits and their relative shares of the benefits. On this basis, the commercial fishery would pay that portion of the cost that is proportional to the share of economic rent in total economic value. Recreational anglers would fund that portion of the cost that is proportional to the share of indirect use values in total economic value. If significant external benefits accrue to society outside of the commercial and recreational user groups, society and NGOs would fund that portion of total programme cost that is proportional to the share of existence value in the total economic value.

Another principle that could contribute to payment design is to design the programme to signal the proper incentives. In principle, those user groups remaining in the fishery would have the self-interest to behave in the socially optimal manner, *i.e.* the objectives that have been set for the buyback programme. When user groups fund all or part of the buyback programme, confronting these user groups with the full costs and benefits of their actions helps to ensure that private incentives are aligned with social objectives. The owners of exiting vessels or permits can, in principle, behave in a socially optimal manner, and thereby do not delay or obstruct the programme.

4.3. Purchase of vessels or licences (permits)?

Should the buyback programme purchase the vessel, licence or both? Purchasing only the licence tends to be cheaper than purchasing the vessel, which, in turn, is generally cheaper than purchasing both the vessel and the licence. Licence prices may be set at the market rate (although expectation of increased revenues after capacity reduction may cause licence prices to rise sharply) or at the value required to encourage the chosen proportion of the fishers to surrender their licences (Read and Buck 1997).

Many vessels hold licences for more than one fishery. If the programme buys back only the licence, the vessel remains free to fish elsewhere, and, in doing so, shifts fishing capacity to another fishery. If the programme buys back the vessel, but not the licence, the licence, if transferable to another vessel, can be used with another vessel in the fishery. In this instance, pressures on the fish stocks and economic rents may not be abated, and may even increase if the licence is used with a vessel that is more productive than the vessel that was removed.

Purchasing only the licence frequently removes vessels from the fishery that are inactive or that fish infrequently, but which could potentially increase the amount that they fish if the profitability of the fishery increases. This was the primary purpose of the New England groundfish buyback for permits. Although the average vessel age in the New England groundfish permit buyout was nearly the same as in the subsequent vessel buyout, the average length, gross tonnage and horsepower were all much less. Inactive or low-activity vessels may have their primary focus on fishing in other fisheries, and be holding licences more as options to fish, and the licence price may fundamentally reflect option value. Purchasing the lowest-priced licences tends to remove the least active vessels, such as vessels fishing part time or in multiple fisheries, or which are the most marginal in some other sense.

Purchasing inactive licences affects the long-term effectiveness of the buyback. The long-term effectiveness of a buyback programme can depend upon whether previously inactive vessels or buyback beneficiaries return to the fishery (GAO 1999). For example, the New England groundfish programme purchased 79 vessels, but 62 previously-inactive vessels began catching groundfish, and several participants in the programme used the buyback funds to buy new vessels and return to the fishery.

The licence can be attached to the vessel, so that a separate market for licences does not emerge. The buyback would make no distinction between the vessel and licence, and the buyback price would include the values of the two assets. Fishing capacity would not be allowed to shift to another fishery. If a bought-out vessel also held licences for other fisheries, and these licences were also attached to the vessel, the buyback price could include the licence values from the other fisheries and reflect the expected profitability of the other fisheries.

Multiple licences for the same fishery may be held by a single vessel, in which case it would be said that they are "stacked". When licences are attenuated by limits to capacity, stacking them allows a larger vessel or a greater catch. The buyback price can be expected to increase with stacking.

Economic rents from a fishery are capitalized into all capital assets, which in the fishery without some form of private or common property right for area or catch, are the vessel and licence. Rising economic rents following a vessel buyback programme would consequently lead to rising values of the vessel and licence. Purchasing only the vessel leaves the licence as the recipient of any gains in economic rent, reflected by a gain in licence value. Purchasing only the licence leaves the vessel as the recipient of any gains in economic rent, reflected by a gain in vessel value.

Other considerations arise when deciding whether to buy back vessels or licences. There is a trade-off with affordability, since it is less expensive to buy permits. Another factor is whether there is strong spillover onto other fisheries. Also, if the permit is removed from the vessel through the buyback, can the vessel still participate in other fisheries? Part of the answer relates to the scope of the programme.

4.4. Voluntary versus mandatory participation

Virtually all licence and vessel buyback programmes have been designed on the basis of voluntary participation. One of the few buyback programmes with mandatory participation was that for the Northern Australian prawn fishery, which was discussed extensively by Holland, Gudmudsson and Gates (1999). In this fishery, fractional licensing (Townsend and Pooley 1995, Cunningham and Gréboval 2001, Joseph 2005), in which vessels were required to purchase 30 percent of their vessel units from other vessels to remain in the fishery, was used. The Japanese longline buyback programme made provisions for mandatory participation should a sufficient number of voluntary participants fail to materialize, but this provision was not required (Kuronuma 1997).

4.5. Conditions on reuse of vessels, gear or licences

Buyback programmes may place conditions on the reuse of the purchased vessel, gear or licence. One of the most important conditions for vessel buybacks is whether it is required that the purchased vessel be scrapped. If a purchased vessel is not scrapped or sold quickly, then the government incurs maintenance costs, losses due to depreciation in value and possible losses due to sinking, burning or running aground. Vessels that are not scrapped or committed to a non-fishery use may be used in another fishery, which itself may face overcapacity and overfishing, thereby simply transferring the problems from one fishery to another, while providing windfall gains to vessel owners whose vessels were purchased and subsequently transferred. Even if a vessel is not transferred, funds from the buyout might be used to purchase a vessel to be used in another fishery.

In the New England groundfish vessel buyback programme, the vessel owner was required to show that the vessel was being scrapped, had sunk or had been committed to some non-fishing use. Most vessels were either scrapped or sunk, with others transferred to non-fishery use. Vessel owners were required to surrender all federal fishing permits and to pay any costs associated with scrapping or transferring the vessel. Nonetheless, several programme participants used the buyback funds to purchase new vessels and return to the fishery. In MAGP I, as in Denmark, France and Italy, the purchased vessels were to be scrapped, transferred to non-fishing uses or transferred outside of EU waters.

Some buyback programmes allow construction of new vessels if the previous vessel is scrapped. There may also be a requirement that the newly-constructed vessel be no larger in terms of GRT or length or some similar measure of vessel size than the scrapped vessel, and may even require removing a greater amount of tonnage or engine power than that of the newly-constructed vessel in an attempt to limit the growth in fishing capacity. The Italian government introduced a moratorium on new licences and a limit on construction of new vessels, whereby building a new trawler was allowed only if a larger vessel, not less than 120 percent of the new one, was scrapped. During the first two MAGP programmes, no controls were in place to prevent the replacement of decommissioned vessels by newly-constructed vessels of the same capacity.

Some buyback programmes restrict the use of the vessel or licence in another fishery in that country. The Norwegian buyback programme stripped the scrapped or transferred vessels of their fishing concessions, *i.e.* their rights to participate in specific fisheries, such as purse seining for capelin, trawling for cod or shrimp, *etc.* Concomitant with these concessions is usually a right to a certain portion of the total quota for one or more fish stocks and so, by nullifying the concession, the quotas of the remaining vessels and their profitability can be increased.

Under the conditions of some buyback programmes, vessels can convert to another activity or gear. Under the Italian buyback programme for driftnet fishing for swordfish, operators chose between the re-conversion or permanent withdrawal from any fishing activities. Vessel owners were entitled to receive a retirement allowance if they permanently exited from any fishing activities or a re-conversion allowance if they continued fishing by shifting to other gear. The Spadare Plan allowances received by vessel owners were related to GRT and the year of participation in the plan, for which the premium decreased if there was late participation. The 129 retirement allowances were greater than the 634 re-conversion ones. Fishers permanently withdrawing from any fisheries and applying for a retirement allowance were required to return both their fishing licences and nets. Those who opted for transfer to another fishery were required to return their nets and driftnet licences. If the converters did not have other extant licences, they were entitled to apply for purse-seine licences or new licences for small-scale fishing gear. Crew members involved in the plan were entitled to receive retirement allowances if they agreed to forgo any fisheries activities or re-conversion allowances if they shifted to other fishing activities involving gear other than driftnets or to other economic sectors.

Some buyback programmes allow the vessel to be exported to another country. The EU MAGP programmes are an example, although vessels under 25 GRT cannot be exported to non-EU countries. The Norwegian buyback programmes allowed the sale of vessels out of the country. If purchased vessels are sold abroad, then there may be simply an export of the overfishing and overcapacity problems if the vessel is used in a fishery with the same problems.

Vessels might be sold to help finance the buyback programme, as in the British Columbia salmon troll buyback. Revenues from vessel sales helped raise funds, but many vessels could not be quickly sold, and the government incurred maintenance costs and losses due to vessels depreciating in value or sinking. The question as to the alternative use of the vessels that were sold remains.

A programme that does not require scrapping may have an impact on the price of the vessel that is to be bought out, and the prices of second-hand vessels may fall. A buyback programme that purchases only the licence does not have to deal explicitly with a bought-back vessel; instead, the decision is retained by the vessel owner, as was the case in the New England licence buyback programme.

4.6. Conditions on reinvestment

Conditions might be placed on reinvestment of funds received by vessel or permit owners, with an eye on limiting expansions in the capital stock and adoption of new technology that is either embodied in the capital stock or is disembodied, such as new ways of fishing. In the Australian South East trawl fishery, the purchase of latent licences, although partially limiting future increases in fishing effort, appears to have facilitated additional investment in the fishery, since public funds obtained from the sale of latent licences were evidently invested by operators in the capacity of active vessels. In the New England groundfish buyback programme, while 79 boats were sold to the government, 62 previously inactive vessels began catching groundfish after the project began, and several participants in the programme used the buyback funds to buy new vessels and return to the fishery (GAO 1999). The British Columbia salmon troll buyback programme required that a vessel owner replacing an existing vessel with a larger one was required to purchase another licensed vessel of such size that the gross tonnage of the two existing vessels was greater than or equal to that of the replacement vessel.

4.7. Buyback price formation process

An important programme design issue is the price formation process for the vessels, licences, fishing rights or gear to be purchased. There are many different ways to design this process, but in all instances a cost-effective process more efficiently removes fishing capacity. Some of the key issues include the programme seeking bids or making offers, single price or reverse auctions, single or multiple rounds of bidding, sealed or open bidding, irrevocable bids, whether bids are responsive or non-responsive to the criteria and conditions established, the length of the bidding process and buyback programme and how much bids must be beaten by. The programme designers have to decide which approach mobilizes support for the programme, is more cost-effective and fits the budget.

There are several different price formation processes. Consider first reverse auctions, in which operators submit confidential bids to the scheme, the lowest bid wins and that operator is paid that lowest bid. Additional information may be required to help discriminate between the bids and achieve the greatest impact for the least cost, such as different metrics as discussed below. Second, the buyback programme may establish an offer price, which vessel, licence, or gear owners are free to accept or reject. Third, in sealed bid auctions, the bidder with the highest sealed bid wins and pays that bid. Vickrey auctions have a second price, sealed-bid format. The bidder making the highest bid wins, and pays the next highest bid.

A reverse auction is the most widely-used process to form prices. This process is called a reverse auction because a single buyer receives bids from several would-be sellers and chooses the lowest bid, whereas in a standard auction a single seller receives bids from several would-be buyers and chooses the highest bid. Bids are usually sealed. The buyback programme may calculate and offer single-round prices, which asset owners are free to accept or reject. The programme's offered buyback price may not equilibrate supply and demand, and the number of applicants can exceed or fall short of the funds available.

Price and distribution can be affected by eligibility requirements, bid ranking systems and direct allocation of funds among groups. The scoring or ranking of bids affects who stays and who exits, *i.e.* the composition of the remaining fleet, and the amount by which the total capacity is reduced. A problem with most bid systems involving the sale of a vessel is that everyone offers a different product – there is not a homogeneous metric. However, the use of units of length, GT, GRT, fish-carrying capacity, revenue or fishing capacity militates against this problem. If licences are for a given category, then the licences are closer in equivalence than simply vessels, and hence easier to judge and require less information.

Buybacks can occur all in one round – the "Big Bang" option – or in multiple rounds. There are advantages and disadvantages to multiple- and single-round buybacks, and, in practice, the availability and timing of funding often determines which approach is adopted.[6]

5. VESSEL BUYBACKS IN TRANSNATIONAL FISHERIES[6]

5.1. Introduction

Overcapacity and overfishing in transnational resources spring from the customary right of any state to fish on the high seas. International law, specifically Article 116 of the Law of the Sea, qualified by articles 117, 118 and 119, allows free entry to fish on the high seas. Article 64 of the Law of the Sea mandates international cooperation among nations to manage and conserve tunas, defined as highly-migratory species, but the effects from the absence of well-defined and fully-structured property rights, national sovereignty and jurisdictional issues override Article 64, so that the dominant strategy for vessels and flag states remains largely non-cooperation with regard to fishing capacity. Incentives thus remain to enter the fishery, increase vessel size and adopt technological advances in the race to catch fish. Regulation by TACs and the seasonal closures in the absence of the incentives from well-structured property rights can reinforce this race to catch fish. Prior to the implementation of ITQs in the fisheries of the United States and Canada for Pacific halibut, increasing fishing capacity and decreases in the length of the fishing season in response to this left a remarkably short fishing season in the end.

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[6] This section largely draws from Joseph and Greenough (1978), Barrett (2003), Joseph (2003, 2005), Barrett *et al.* (2004), Joseph *et al.* (2007), Curtis and Squires (in press), Groves and Squires (in press) and Hannesson (in press).

The main institutions are the regional fishery management agreements and their commissions. The primary legal instruments are the Law of the Sea, United Nations Implementing Agreement, and the FAO Code of Conduct for Responsible Fisheries. Some regional fishery management organizations allow for trade sanctions among member parties. Sovereignty and failure of custom require transnational externalities be resolved through international cooperation (Barrett 2003, 2005).

Unilateral buybacks in fisheries exploiting transnational resources simply remove fishing capacity from one country, and thereby reduce pressures on profits and resource stocks, which, in turn, allows free-riding through growth in another country's fishing capacity. The Italian buyback of fishing capacity in the drift gillnet fishery for swordfish simply allowed expansions of fishing capacity by other nations fishing for swordfish in the Mediterranean Sea (Spagnolo and Sabatella in press).

The OPRT buyback of high-seas tuna longline vessels in the Pacific Ocean is a second example of a successful buyback in a transnational fishery. Nonetheless, there was some free-riding through expansion of longline vessels by non-cooperating parties in this fishery, which, in turn, militated against some of the gains from the largely unilateral buyback.[7] A key factor contributing to potential success is that Japan is the primary market for sashimi-grade fish, and if that market were denied to a longline vessel, that vessel would face difficulty in turning a profit (Joseph *et al.* 2007). A similar trade restriction, built on a near-monopoly for processing, was one of the key factors contributing to the success of the North Pacific Fur Seal Treaty (Barrett 2003).[8] This treaty deterred entry into the high-seas pelagic sealing industry, effectively transforming open access into common property, improved on unilateralism, and made every party better off by creating an aggregate gain and distributing this gain in such a way that all countries would prefer that the agreement succeed.

Gains to international cooperation through gains from participation and compliance, while deterring entry and expansion by non-parties, are perhaps the greatest challenges to a buyback programme on shared resource stocks such as tunas. Gains to multilateral cooperation from reducing fishing capacity due to a buyback come from saving on losses due to overcapacity and excessive exploitation of common resources, *i.e.* from lowering the losses due to the "Tragedy of the Commons" (Harden 1968).

A buyback programme cannot be successful unless every party is better off with the programme than without it, but to succeed the programme also must ensure that any party would lose by not participating. In other words, free-riding through non-participation must be addressed by some effective means, such as trade restrictions, as noted above. In addition to a negative incentive, a positive incentive for participation comes to the remaining vessels through the aggregate gain from participating, in the form of increased profits, and to sellers of vessels and/or rights through compensation in the form of the buyback payment.

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[7] Joseph *et al.* (2007) observed that Japan has targeted 130 vessels for removal from its fleet, and the Taiwan Province of China has agreed to limit its fleet to 600 vessels. The latter will require that Taiwanese-owned vessels under flags of convenience be transferred to its registry. Some of the recalled vessels will be bought back and scrapped, along with the 130 Japanese vessels. Moreover, funds were loaned to the industry groups by the Japanese government on a 20-year payback schedule. This buyback was partly in response to the reduction of fishing areas when national waters were extended into what had been international fishing grounds (Holland *et al.* 1999).

[8] Virtually all processing of Pacific fur seal skins took place in London, giving a credible threat to restrict trade (Barrett 2003). Article III of the North Pacific Fur Seal Treaty banned imports of non-authenticated sealskins (the skins of seals killed by non-parties to the treaty). The trade restriction deterred entry by non-parties into the pelagic sealing industry because the entire pelagic harvest of sealskins was processed and sold in London. The treaty went a step farther. "Implicit in the original treaty is also a kind of "Grim" strategy calling for complete dissolution of the agreement and, by implication, a reversion to the disastrous open-access outcome, should any of the parties withdraw at a later date" (Barrett 2003: 36). The treaty also allowed the signatory countries to seize a violating vessel of another signatory country and deliver it to the authorities of the country in which it was registered, who were bound by their own domestic laws to tackle the issue.

5.2. National sovereignty: individual vessels or flag states?

National sovereignty complicates buybacks in transnational fisheries. Buybacks and the critical preconditions of limited access and vessel registration can be defined either in terms of the individual vessel or the flag state. In other words, what is the basic unit in the programme, flag states or vessels, with their associated measures of fishing capacity (potential output, GRT, fish-carrying capacity, length, *etc.*)? Can vessels and their associated measure of capacity freely transfer among flag states, or are vessels and their associated capacity directly tied to the flag state? The Inter-American Tropical Tuna Commission (IATTC) developed its Regional Vessel Register, incorporating the concept of transferability, but there has been reluctance on the part of some states to recognize this provision of the programme. Strictly on the grounds of economic efficiency, a limited access and vessel buyback programme defined solely in terms of vessels, rather than flag states, can be expected to lead to greater economic rents and healthier overall profits in the fishery, since there can be greater gains from trade (arbitrage efficiency) as capacity and the right to fish shift to lower-cost vessels.

5.3. Coastal and distant-water states

An additional issue that arises is the distribution of vessels and fishing capacity among coastal and distant-water states, and, more generally, the unique nature of the required multilateral cooperation to manage fishing capacity when there is asymmetry among states. This issue is not unique to fisheries. Major international environmental agreements, such as the Montreal and Kyoto Protocols, addressed similar asymmetries between developed and developing nations with global atmospheric public goods. Coastal states control entry into their EEZs, and special privileges are enshrined in international law.[9] Potentially viable limited entry and buybacks must allow for the increases in numbers of vessels and expansion of fishing capacity by coastal states, a measure taken into account by the IATTC, for example, in its Regional Vessel Register and capacity limitation. This provision represents side payments and strategic choice in response to the asymmetries between coastal states and distant-water fishing nations.[10] This provision also reflects an implicit agreement about use and property rights, beginning a transformation from open access to common property.[11] This provision ensures that the countries that might otherwise lose, instead gain, by participating,. Side payments help ensure that each country would lose by not participating, given that the others have agreed to participate. Side payments are thus a strategic choice, and can redefine the cooperation problem, making participation in the interests of developing countries.

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[9] Joseph *et al.* (2007) state, "Articles 56 and 61 of the Law of the Sea recognize the rights of coastal states to control access to the waters under their jurisdictions, and therefore to decide who can fish for tunas in those waters, with the caveat (Article 62) that, if the resource is not fully utilized, access to fish must be provided to the vessels of other states."

[10] Side payments have both distributive and strategic functions in conditions of asymmetry in international environmental agreements (Barrett 2005). Side payments help increase participation and make agreements fair. Side payments, by which gainers of a policy can compensate those who bear the burdens, help ensure that nations that would otherwise lose, instead gain, by participating. Side payments redistribute the additional gain from cooperation and help guarantee that all parties are at least as well off as before cooperation.

Open access is a form of property right, but one in which no individual, group or state has exclusive use, so that entry to the resource is open. Common property is a form of property right in which exclusive use of the resource is vested in a well-defined group, *i.e.* is commonly held. In this case, the group is the signatories and cooperating parties of the IATTC. The common "ownership" is due more to custom than to binding international law, so that exclusive use is through the IATTC, and exclusive use by this group does not provide for full deterrence of entry (and where any trade measures, acting as credible threats, apply only to group members, and not to non-members). Baland and Platteau (1996) provide considerable discussion on this general topic, and they make it clear that common property or use rights with effective management can lead to economically efficient outcomes equal to individual property or use rights, such as ITQs.

Several forms of side payments are possible, including provision for room to grow for coastal states, decommissioning part of the capacity of distant-water fishing fleets and assessing distant-water fishing fleets at a higher rate than coastal fleets in industry-financed buyback programmes. As with the Montreal and Kyoto Protocols, side payments can be made for technology transfer, or multilateral funds can be used to finance continued growth by, in this case, coastal states. Limited allocation of unused capacity to coastal states creates a reserve held by these states, and is a form of side payment; just such an approach was adopted by the IATTC with fish-carrying capacity (Joseph *et al.* 2007). New entrants can purchase or lease this capacity, with the proceeds accruing to the coastal states. Alternatively, a limited percentage of licence or capacity units, with limited duration of the right, could expire on a periodic basis, requiring repurchase for continued use or purchase by new entrants. Similar features appear in Chile's ITQ programme, for which this use right has a staggered and limited duration. New entrants might also be required to purchase additional units of capacity, and retire some portion of the excess. Similar restrictions might apply to reinvestment, such as "stretching" of an existing vessel. Fractional licensing is another possibility, and an alternative to vessel buybacks. Vessels are allocated only some fraction (not the entire amount) of the access right required for the fishery, and must purchase the remaining amount from other, existing vessels (Townsend and Pooley 1995, Cunningham and Gréboval 2001, Joseph 2005).

Reflagging can complicate the definition of a coastal and a distant-water state. In other words, coastal states with unused capacity, or, perhaps more accurately, the right of access measured in units of capacity (vessel size), allowed by a regional fishery management organization can invite vessels from distant-water fishing nations to fish under coastal state flags.

Illegal, unregulated and unreported (IUU) fishing can also undermine the effectiveness of any buyback programme established under the auspices of regional fishery management organizations. Multilateral buybacks, and capacity reduction measures in general, by member and complying nations and parties, can be undermined by IUU fishing, since cooperating parties may be deterred when uncooperative nations reap the external benefits flowing from the sacrifices of cooperating parties, *i.e.* there is free-riding, and the transnational externality remains.

5.4. Limited access: a critical precondition for buybacks

The ability to legally deter free entry into a fishery by new vessels under existing international law is a critical precondition for a buyback. Evolving customary law may be reshaping conditions to deter free entry through the formation of regional vessel registers in the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the IATTC, the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Indian Ocean Tuna Commission (IOTC).[12] Joseph *et al.* (2007) observe that, "… ICCAT and IOTC maintain 'positive lists' of vessels that are authorized to fish in the waters under their responsibility; vessels not on those lists would not be authorized to fish in the Atlantic or Indian Oceans. However, the lists do not limit the numbers of vessels that can be on them. New vessels can be entered on the lists if they meet the qualifications prescribed by the regional tuna bodies."

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[12] Among the 16 coastal states comprising the Forum Fisheries Agency, the 1992 Palau Arrangement for the western and central Pacific purse-seine fishery by 8 members has the objective of limiting the level of purse-seine fishing in the region. The Palau Arrangement establishes a limit of 205 purse-seine vessels that will be licensed by the parties for fishing in their EEZs. The majority of the catch of tunas from the area is taken in the EEZs of these eight members.

The IATTC register goes a step further with a moratorium on fleet growth through numbers and carrying capacities of vessels, where expansions by coastal states are allowed in the IATTC programme. The IATTC register has begun the transformation of open access on the high seas into nascent common property, but through custom, rather than formal international law. The IATTC register allows for transfers of existing vessels to other parties, which provides opportunities for states desiring to acquire fleets, but the capacity quotas remain vessel-specific (new quotas are allocated only when vessels are retired).[13] Such a register essentially places a moratorium on fleet growth in vessel numbers and carrying capacity. Beginning in 2003, the IATTC went farther still, instituting temporary closures and prohibiting "... landings, transshipments and commercial transactions in tuna or tuna products that have been positively identified as originating from fishing activities that contravene this resolution ..." The new resolution instructs parties and cooperating non-parties to comply with the agreement, but there is no mention of penalties to be paid. Most importantly, perhaps, there is no mention of whether and how the rules are to be enforced if they are not followed by non-cooperating parties.

In effect, implicit recognition is growing that treaties are weak instruments for limiting transnational fishing, and recognition is growing that extending and strengthening rights of access through a form of limited entry is critical. Use rights in the form of rights of access and magnitudes of fishing capacity are emerging. (As discussed below, Dolphin Mortality Limits are another form of use right that also developed in the EPO.) Relations among participants are restructured in the process. These programmes represent necessary *de facto*, if not *de jure*, attenuation of national sovereignty within EEZs, and especially on the high seas, beginning a transformation from open access to nascent common property, *i.e.* a transformation from free entry to the resource to exclusive use of the resource by a well-defined group and a form of rights-based management.[14]

Qualification for eligibility in a regional vessel register is another issue. Joseph (2005) observes that to qualify to be entered on the register a vessel would have to be considered to be actively fishing, and that this term requires definition. To remain on the register, a vessel would have to continue to be active, according to the same or a similar definition. Establishing such a requirement would prevent vessels that had not been fishing from adding more capacity, and would prevent a flood of vessels from entering a fishery as soon as the intention to limit capacity became public knowledge.

The growth of market mechanisms, whereby new entrants and existing fishers purchase the right to fish—licences and capacity units—from existing participants, can provide a decentralized mechanism to facilitate new entry or expansion by current participants. Such market mechanisms are most efficient when licences and capacity units are not tied to flags. If this feature of transferability were not retained, the effectiveness of the system would weaken, and there would be less economic efficiency than would otherwise be the case. The result would be a limit on fleet size that was fixed among nations and could be not changed without difficult and time-consuming negotiations. Compliance can make a key contribution in this case, with the CCSBT, the IATTC and ICCAT allowing for trade restrictions, but only among member countries. The IOTC requested that nations participating in the Record of Authorized Vessels of greater than 24 meters in overall length to close ports to and prohibit imports from vessels involved in IUU fishing, and not grant the use of their flags to vessels that had been involved in IUU fishing unless the ownership of the vessel had changed (Joseph *et al.* 2007).

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[13] Joseph (2005: 292-293) observes, "The RVR [regional vessel register] provides a mechanism for fixing the fleet of purse-seine vessels operating in the EPO at its current size, with an allowance for minimal expansion to fulfill the needs of several coastal states. An important feature of the arrangement is the provision for allowing vessels to transfer among the participants. Once a vessel is listed on the RVR it is authorized to fish in the convention waters. If a vessel is removed from the RVR by its flag state it can no longer fish in the area. As long as a vessel is on the RVR it can move from flag to flag. When a vessel transfers from the flag of one participant to that of another it stays on the RVR and its capacity 'quota' is transferred with the vessel. Similarly, if a vessel on the RVR is replaced, or its well capacity is increased, a vessel of equivalent size, or an amount of capacity equivalent to the increase in size, must be removed from the RVR. In a manner of speaking, the RVR creates a market for trading capacity. A vessel owner or a nation desirous of increasing its capacity can offer to purchase vessels listed on the RVR. When purchased, the vessel, which would remain on the RVR, along with its capacity quota, would go to the purchaser. Once the RVR was established through political negotiation, theoretically, any changes would result from market forces."

[14] As Baland and Platteau (1996) make clear, rights-based management not only entails only use and property rights for individuals, such as ITQs, but also use and property rights held by well-defined groups, giving common use and property rights. Baland and Platteau further make it clear that commonly-held resources with effective management can lead to fully efficient resource exploitation.

5.5. Financing the buybacks

Buybacks within regional vessel registers that limit entry can be financed, in part, by industry participants, perhaps seeded by an initial low-interest loan by a development bank or consortium of governments. In fact, the World Bank observes that, in view of the high level of funding required and the policy nature of those schemes, it and other major international financial institutions could support buybacks of surplus vessels through broad-sector instruments, such as Sector-Wide Approach programmes (SWAPs), Poverty Reduction Support Credits (PRSCs) or perhaps even the Global Environmental Facility (GEF) (World Bank 2004).

Buybacks aimed at protecting ecosystem health (environmental public goods) can, in principle, be legitimately financed by governments and international public institutions to the extent that these funds reflect the public's willingness to pay for the "existence value" of the ecosystem's health. In principle, buybacks financed by governments solely for capacity reduction without loan repayment constitutes a subsidy, but since government subsidies contributed to the overcapacity problem, government subsidies may be called for, in part, to correct this problem. As the fleet was reduced towards the target size, the average catch per vessel would increase and profits would rise, so that the industry can better fund the buybacks. Thus the initial loan and on-going payments for buybacks could be funded by an assessment on each vessel; a landings tax would raise funds proportional to the amount of fishing. Increased profitability with success of the buybacks would provide the fundamental pool of funds. Alternatively, as Joseph (2005) notes, all or part of the tax or assessment could be applied to the processed product, since the processors would reap the benefits of a well-managed fishery. Ultimately, the relative price elasticities of producers, processors and consumers would determine the allocation of the tax among these groups. The assessments and development of a pool of buyback funds would be region- and gear-specific.

Recreational fishers could also be expected to contribute to financing the buybacks, thereby reflecting their share of the resource's exploitation. Such co-financing of a buyback occurred in the Texas shrimp fishery (Riechers, Griffin and Woodward in press).

5.6. Other issues

In addition to limited licences and access, still another critical precondition in transnational fisheries may be management of capacity units, denominated in one or more measures of vessel size. The traditional response in such fisheries has been changes in vessel design and increases in other dimensions of the multi-dimensional capital stock (*e.g.* increasing GRT and engine power when vessel length is limited) and accelerated adoption of technical advances (*e.g.* improved electronics or fishing for fish associated with fish-aggregating devices (FADs)). Nonetheless, if limited access is the best that can be expected in the foreseeable future, limits on growth of measures of fishing capacity may be the preferred, albeit imperfect, management option. Replacement of existing vessels with new vessels might be restricted to vessels of the same size (within some tolerance) unless the licence for a second vessel is purchased to provide the necessary magnitude of capacity units to support a larger replacement vessel.

The establishment of regional fishery management organizations for the highly-migratory species in the different ocean basins did not fully eliminate the transnational externality, which has implications for buyback programmes. In the Pacific, the IATTC and the Western and Central Pacific Fishery Commission (WCPFC) manage the highly-migratory species in the eastern and the western and central Pacific Ocean, respectively, and yet uncertainty remains as to whether there are biologically distinct stocks of fish in the different jurisdictions. Coordination is therefore required between the two regional fishery management organizations. Buyback programmes in one part of the Pacific might, in principle, remove only some of the fishing capacity creating fishing mortality on common resource stocks. More critically, vessels harvesting highly-migratory species are highly mobile, and readily travel from one part of the globe to another. Control of fishing capacity by one organization may simply create spillovers to other regions and regional fishery management organizations as vessels fish in other areas and/or change their flags. The potential also exists for vessels to enter IUU fishing.

Ex-vessel markets for industries exploiting highly-migratory species are global, and ex-vessel markets are spatially linked by prices.[15] In other words, prices formed in one part of the world either follow or lead prices in other parts of the world. Hence, buybacks intended to lower fishing capacity, and thus catches of highly-migratory species, to increase ex-vessel prices and revenues must contend with a global market in which ex-vessel prices are influenced globally, rather than an isolated regional market.

6. BUYBACKS TO ADDRESS ENVIRONMENTAL ISSUES

The capacity issue in some tuna fisheries extends beyond more than simply the total level of fishing capacity necessary to sustainably harvest the target tuna species and ensure a profitable fishery. The capacity to catch all species, both target and bycatch, is also critical. In the IATTC region, for example, some vessels set on tunas associated with dolphins to harvest the larger yellowfin tuna (*Thunnus albacares*), some vessels set on free-swimming schools of tunas and some vessels set on tunas associated with flotsam and FADs. Sets on dolphins incidentally surround dolphins in the nets (although practically all of these are released unharmed). Sets on flotsam and FADs, which target skipjack tuna (*Katsuwonus pelamis*), incidentally harvest small yellowfin and bigeye (*Thunnus obesus*) tunas, leading to discards, and a wide range of non-target species, including billfishes, sharks, mahi-mahi (*Coryphaena* spp.), wahoo (*Acanthocybium solandri*) and sea turtles (Hall 1998).

Reductions in the total level of fishing capacity through general buybacks can directly reduce catches of non-target species (as well as the targeted tunas), and thereby help improve ecosystem health, but the amount of reduced overall fishing capacity may be insufficient to fully address this environmental issue. Buybacks of vessels and/or use rights—the carrot approach—can instead specifically target vessels harvesting in ways or with gear that have the most detrimental ecological impacts in sectors of the fishery facing the greatest environmental issues. Historically, economic incentives to address environmental issues, such as incidental takes of dolphins or sea turtles taken when shrimp trawling, have generally relied upon negative economic incentives—the stick approach—through trade measures and boycotts (*cf.* Joseph 1994, Headley 2001).

Dolphin Mortality Limits (DMLs) are an example of an annual use right. The owners of vessels might accept payments for the vessels to refrain from fishing—their use rights are bought back—or even leave the FAD fishery entirely—their vessel and/or use right to fish are bought back. Compensation and funding the buyback might be arranged by a collective assessment on the entire fishery, or only those actually participating, and used for buybacks of vessels, or simply their use rights, for that method of fishing. Partial funding by governments or international institutions would legitimately reflect the public's valuation for the "existence value" of ecosystem health. In this manner, buybacks of vessels and/or use rights provide positive economic incentives. Use rights, such as DMLs, also provide negative economic incentives, in that failure to conserve dolphins, that is, mortality in excess of the DML, costs the vessels forgone revenues from forgone catches by terminating fishing. DMLs (and prior to their establishment the threat of trade sanctions and consumer boycotts,) also induced changes in technology, such as the backdown procedure and the Medina panel.

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[15] Formally, the spatial linkages of ex-vessel markets for tunas and swordfish set the conditions for pecuniary externalities

Buybacks of vessels and/or use rights might also indirectly help address environmental issues, through strengthening economic incentives and fostering cooperative self-organization to tackle the environmental issues. By improving the economic returns in the fishery, helping to dampen the race to catch fish and providing a means of compensation, buybacks can help to foster cooperation among fishers to voluntarily address bycatch and environmental issues (and also general overcapacity).[16]

Because protective measures can be costly, fishers may not undertake them unilaterally or voluntarily, particularly under conditions of open access. However, a growing literature in the field of environmental economics suggests that voluntary approaches to environmental protection can be effective under certain conditions, even when protective measures are costly (Segerson and Miceli 1998, Segerson and Dawson 2001, Segerson and Wu in press).[17] Incentives for voluntary protection can exist, for example, when governments threaten to impose more costly command-and-control regulatory actions or protective measures if voluntary approaches are not successful in meeting protection targets. Threats of embargoes and trade measures can also be effective, as with the dolphin-tuna and shrimp-sea turtle issues (Joyner and Tyler 2000). These incentives can be created either at the level of an individual vessel, such as occurred when vessels reduced dolphin and sea turtle mortalities through technological and other innovations, or for a group of firms or the entire fishery, such as when the environmental performance of a subset of vessels affects all vessels in the group or industry. When there are group incentives, free-riding can arise, and must be addressed.

The voluntary Agreement for the Conservation of Dolphins ("the La Jolla Agreement") of 1992, which established the International Dolphin Conservation Program, helped conserve dolphins, and established use rights in the form of Dolphin

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[16] GAO (2001: 6) observes, "The Bering Sea pollock buyback addressed the race to fish that had previously existed among factory trawlers by facilitating the creation of a fishing cooperative by the owners of the remaining trawlers. This cooperative was designed to eliminate the race to fish by assigning a specific amount of fish, or an allocation, to the cooperative, which divides the allocation among its members. Because of this allocation, members of the cooperative have no incentive to expand fishing capacity to catch the available fish before someone else does, as they have in another fishery. Members are able to catch their individual fish allocations at their own pace, at lower capital and operating costs, while increasing product quality. These changes resulted in higher profits and longer fishing seasons for the remaining factory trawlers."

[17] Voluntary agreements: encourage pro-active cooperative approaches from industry, greater flexibility and freedom to find cost-effective solutions that are tailored to specific conditions and the ability to meet environmental targets more quickly, due to decreased negotiation and implementation lags. Voluntary agreements can be classified as either those that induce participation by providing positive incentives, such as cost-sharing or other subsidies (the carrot approach) and those that induce participation by threatening a harsher outcome (such as regulations) if a voluntary agreement is not reached (the stick approach). Voluntary agreements are also widely used to reduce agricultural pollution and induce conservation (Segerson and Micelli 1998).

Mortality Limits (Headley 2001).[18] Self-enforcing group voluntary agreements are currently employed, for example, by a group of New England longline cod fishers; these fishers contract with the regulatory body to self-manage their share of the TAC, and have signed binding contracts with each other for self-enforcement. The fishing cooperatives authorized by the American Fisheries Act are another example. Similar arrangements could be made to manage incidental takes of non-target species for vessels setting on floating objects, in which contracting parties agree to reduce bycatches. Vessel owners, for example, can voluntarily enact time-area closures for sets on floating objects when bycatches are deemed highest and institute skipper training programmes.[19] Again, compensation for some or all of the reduced revenues might be arranged by a collective assessment on the entire fishery and/or buyback of vessels, or simply their use rights for that method of fishing. Financing can come from governments or international organizations to reflect the public's "existence value" for environmental public goods. Buybacks contribute by reducing the numbers of vessels and strengthening the profitability of the fishery.

As a variation, a possibility adopted from the British Columbia Mifflin Plan is possible (*cf.* Grafton and Nelson in press). The EPO fishing area could be divided into areas for the different types of tuna fishing, *e.g.* an area for dolphin fishing and another area for FAD and flotsam fishing. A vessel licence holder would then be required to select one area, with the licence being good for that area only. The scheme would permit licence holders to purchase licences from other holders. In so doing, the purchaser would be enabled to fish in additional areas, or with other modes of fishing. This provision, popularly known as "stacking," would work as follows: The owner of a purse-seine vessel, initially required to choose between one of two areas, could opt for the area with dolphin fishing, and then purchase a licence from the owner of a purse-seine vessel harvesting in the area with FADs and flotsam. The purchaser could then fish in both areas. Capacity is reduced because the seller's purse-seine vessel is removed from the fleet, with the "stacking" of the two licences onto one vessel. Dividing the fishery into smaller areas and gear groups helps limit the number of players, thereby contributing to more cooperative behavior.

Fractional use rights to fish in an area and/or with certain types of gear are another possibility. Fishing would require purchasing additional fractional use rights. Buybacks to permanently retire some of these fractional use rights would complement the programme.

The buyback programme in the Australian northern prawn fishery helped reduce environmental damage through reduced bycatch and protection of sensitive sea grass beds (World Bank 2004). Similar terrestrial programmes include the Conservation Reserve Programme of the United States Department of Agriculture, Wetland Reserves and Nature Conservancy reserves, and New York City's purchase of watersheds in the Catskill Mountains (Heal, 2000). While property rights are often required on land, a limited access programme with spatial and/or temporal dimensions restricting use rights could serve a similar role.

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[18] DMLs are use rights allocated to nations and, subsequently, to vessels. These use rights are not transferable, provide exclusive use by a vessel for one year and are not divisible beyond a single dolphin. In addition, the voluntary program became binding formal international law with the Agreement on the International Dolphin Conservation Program (AIDCP), which entered into force in February 1999.

[19] For example, Hall (1998: 27-28) states, "However, in the eastern Atlantic, where FADs have been used intensively, the majority of the tuna vessel owners operating there have implemented a voluntary ban on the practice in a time-area stratum (A. Fonteneau, pers. comm.), which suggests that they perceive the negative effects of the practice to be quite significant. Experiments are needed to answer this question."

7. ISSUES FROM AN INDUSTRY PERSPECTIVE

From an industry perspective, whatever programme is put together must make sense to the participants. This is a particularly important issue if the buyback programme is industry initiated and financed. The participants must buy in and understand that a buyback programme must take place.

Industry support requires finding a champion, because leadership is required to bring a buyback programme to fruition, particularly if the programme is industry-financed. Such a focal person helps to ensure that the necessary steps occur throughout the process. The leadership can come from industry, government or even NGOs. In most instances, government agency support is required, since they are typically the programme administrators.

Dealing with non-supporters throughout the process is an important leadership element in any buyback programme, since not everyone will agree with the programme. Some non-supporters will become deterrents. Non-supporters can come from the fishery in question or from people outside of the industry who are sincerely opposed to such an approach.

Flexibility is required throughout the process, since the unexpected will inevitably arise. This flexibility may require retracing steps, or even starting all over. Fishers and governments must support the buybacks and must realize that change must occur and that the process is not arbitrary.

8. WHAT ARE THE MAIN LESSONS TO BE LEARNED FROM THE INTERNATIONAL EXPERIENCE?

The global survey of buyback programmes for vessels and licences offers the following lessons (Curtis and Squires in press).

First, and one of the most important lessons, it is much easier and less expensive to prevent overcapacity and overfishing than to initiate an *ex-post* reduction.

Second, there are several critical preconditions for buyback programmes to be effective. Proper registration of licences and vessels creates a well-defined group of eligible owners, and provides well-defined boundaries to the fishery and the programme. Limited access is another critical precondition. Unless entry is deterred, the conditions for free-riding will be established. Vessels will enter the fishery as profits rebound following the capacity reduction induced by buybacks, and fishing capacity will increase.

Third, buybacks can play a strategic role as a transition to longer-term conservation and management, predicated on enhanced use or property rights (whether private or common and on catches or on areas, as in marine reserves). Buybacks have been applied, with the exception of the ITQ fishery in South East Australia, to fisheries with incomplete property rights. The constraints imposed by such use or property rights mean that buyback programmes can be seen as an important strategic tool, because to induce a change in behavior requires a change in incentives. In other words, buybacks are introduced because of dissatisfaction over the *status quo*, and hence buybacks can present a real opportunity to restructure incentives so that private economic incentives of fishers are more closely aligned with social goals of reduced capacity, reduced fishing mortality and lessened environmental damage.

Buybacks accelerate this transition and restructure incentives and relations among participants by improving economic conditions during a window of opportunity following a buyback. If buybacks sufficiently reduce the number of vessels, and profits sufficiently rebound, the remaining participants are likely to be the most committed to the programme and to most enjoy the growing cooperation and more favorable attitudes towards more complete property rights. Industry-financed buybacks, as a collective, rather than a private, debt responsibility, and as an alternative to public funding, also help nudge incentives to shift behavior from uncooperative to cooperative.

Ultimately, because buybacks do not change the underlying property rights, buybacks in and of themselves do not, over the long run, address the incentives to over-invest in an open- or limited-access fishery, and they eventually help aggravate the problem by strengthening investment incentives through growing profits.

There are several different ways to induce change through the choices that are made for the design of a buyback programme. These design choices are strategic choices, and thereby can be viewed as opportunities to restructure incentives and relations among those remaining in the fishery. Every substantive choice can affect incentives, and thereby the behavior of the remaining participants, and even the decision as to who chooses to stay in the fishery and who chooses to leave it through participation in the programme.

Linkages of programme design features can also be a strategic choice. For example, requiring that the purchased vessels be scrapped or preventing the owners of purchased vessels from using the proceeds to reinvest in the fishery affect not only the level and growth of fishing capacity, but can also affect who elects to participate, the purchase prices and the fishing capacity and profits.

Fourth, buybacks work best through co-management, *i.e.* cooperation between the public and private sectors and other interested parties. Strong industry participation in all phases of the programme increases the chances for success. Consultations and workshops with user groups help design better programmes, prepare the user groups for the buyback and help build and enlist support from user groups.

Fifth, moral hazard issues may arise. The purchased vessels are frequently older and less productive than the remaining vessels. The buyback may merely accelerate the departure of vessels marginal to the fishery that would have departed in any case; the buyback facilitates and accelerates their exit, and at a higher purchase prices than would otherwise have been the case. The purchased vessels or licences may also have been among the least active ones, in which case the buybacks would have had little effect in improving economic performance and helping the resource stocks to recover. By absorbing risk, buybacks may also strengthen investment incentives for the remaining vessels.

Sixth, there is often no single, best answer to many programme design issues. Nonetheless, clear objectives and a clearly-defined scope of the programme are critical. A pilot programme can also be helpful. One or more champions—individuals, organizations or public agencies—can play an important galvanizing force.

Seventh, decisions must be made as to whether to first purchase active or inactive vessels or permits or both. Purchasing inactive vessels and/or permits is cheaper, and can allow ready expansion of fishing capacity as profits rebound and fish stocks bounce back. In most instances, vessels and their permits are purchased together, rather than simply the permits, since removing the vessel eliminates capacity and any spillover effects on other fisheries.

Eighth, the beneficiaries of a buyback programme can contribute to the funding of the programme, all or in part. Commercial fishers can enjoy increased profits, recreational anglers can benefit from higher catch rates and the general public and NGOs can gain from non-market benefits, such as increased ecosystem health. The initial funding for a buyback, especially when the fishery is unprofitable, may have to be a loan from a national or state (regional or provincial) government or, in the case of transnational fisheries, from an international organization. To some extent, public funding can be viewed as compensation for past policy errors. Public loans to user groups mean that the public bears the risk of the loan. Public outlays can be recovered through user fees, such as licences or entrance fees to marine parks, and landings taxes, so that those enjoying the greatest revenue and revenue increases bear the greatest financial responsibility. Public funding without repayment from rent increases is ultimately a transfer payment, which can be capitalized into licence or vessel values and could have a more productive use elsewhere in the economy.

Ninth, the administration of payments and the bidding process are critical issues. Should buybacks proceed on the basis of bids by vessel or permit owners or offer prices determined by the programme? Capacity is usually purchased through vessel, licence or gear bids and reverse auctions, and often on the basis of some metric of fishing capacity, such as dollar bid offered per GRT, horsepower, revenue, catch, fish-carrying capacity, length, *etc*. Bids can be in a single round or multiple rounds. Multiple rounds of buybacks increase administrative costs, but may also reduce strategic behavior in offers. Multiple rounds also allow adjusting payments to target particular groups of fishers by adjusting the criteria for bid acceptance and allowing fishers to reformulate their bids. Bids are typically sealed. Buybacks occurring over a longer time period and at times when fishery regulations are stable can facilitate making better assessments of the benefits of retiring or remaining in the fishery. Irrevocable bids prevent "stink bids", in which speculators bind up a large proportion of the available funds. The programme administrator can help owners form price expectations and markets to form by working to lower transactions costs and releasing average price per unit of capacity, total available funds, *etc*.

Tenth, selective buybacks can help achieve social objectives other than efficiency and resource conservation goals, including recognition of aboriginal treaty rights, accommodation of new entrants and coastal states and shifting capacity regionally, by gear type, or between commercial and recreational fishers. Buybacks provide a compensation mechanism for those in the industry who would otherwise lose out from rebuilding fish stocks and restructuring the industry. Buybacks have different impacts on gear types or regions, but maintaining an equitable allocation of harvests among gear types or regions helps ensure political support.

Eleventh, buybacks have been focused largely on overcapacity, overfishing, raising profitability and disaster relief, and have seldom been intended to address goals of ecosystem management. General buybacks are a blunt instrument, but to the extent that they can target selective areas or times fished, gear types or modes of fishing, buybacks can provide a tool towards restoring ecosystem health. For example, the creation of marine reserves without removing overcapacity, and especially displaced fishing capacity, simply bunches capacity upon the remaining areas; buybacks can help remove some of this overcapacity. Buybacks targeted at methods of fishing, such as sets on floating objects, can reduce bycatches.

Twelfth, buybacks for fisheries exploiting transnational resource stocks are unlikely to be effective without a coordinated management effort among the countries contributing the bulk of the fishing capacity; unilateral buybacks, in contrast to multilateral buybacks, eventually face failure. Buybacks in transnational fisheries must also deter new entrants other than through purchase of licences, which requires changes in, at a minimum, customary international law. Allowing capacity to transfer among individual owners, rather than restricting them to flag states, allows more efficient capacity reduction. Coastal states, when resource stocks span both EEZs and the high seas, are typically afforded special accommodation for growth, which can represent a side payment and strategic choice.[20] They also reflect an implicit agreement about property rights, and ensure that the countries, which could otherwise lose by participating, instead gain. Side payments can also redefine the cooperation problem, making participating in the interests of developing countries.

Thirteenth, buyback programmes usually represent only a second-best outcome. They alone are not the long-term solution to the overcapacity and overfishing problem in an open-access, or even a limited–entry, fishery, although they may be the best solution available in the foreseeable future for transnational and other fisheries. The underlying ill-structured property rights that create incentives for overfishing and overcapacity remain. Without a change in the underlying economic incentives that fishers face, the benefits of buybacks will be transient as investment and productivity grow over time, fueled inadvertently and in part by the buybacks themselves as outside funds expended during buybacks are reinvested (unless there is a strict prohibition against that). Self-enforcing voluntary agreements among fishers may be an attractive option to effectively establish a form of common-use rights, essentially through custom. The incentives to increase cooperation and establish such agreements can be strengthened by buybacks that restore profitability, reduce the number of participants and leave the most committed participants.

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[20] Similar issues arise with atmospheric concerns, such as greenhouse gasses and the Kyoto Protocol, and ozone-depleting chemicals and the Montreal Protocol (Barrett 2003, 2005).

Fourteenth, buybacks are essentially an input control that addresses primarily the capital stock and only indirectly the relationship between inputs and catches. Under command-and-control input controls, uncontrolled inputs can be substituted for controlled inputs, such as investment in additional capital in the remaining vessels, in which case the capital stock of the remaining vessels may be more fully utilized and fishing capacity increased by fishing longer or technology, such as the addition of vessel electronics, may progress. These expansions in fishing capacity are simply responses to the market incentives and economic signals found when use and property rights are incomplete. Vessel buybacks unaccompanied by a comprehensive use or property right thus have the same shortcomings as limited entry, in that the underlying ill-structured property rights generating incentives for overcapacity and over-fishing remain.

Fifteenth, the long-run success of buyback programmes as a programme in its own right to reduce capacity requires controlling future growth in fishing capacity through restrictions on investment and increased fishing, ideally through positive incentives. When a strengthening of the property rights structure is not feasible or appropriate, other measures can contribute. A critical component is to restrict return to the same fishery by vessels that have been bought out, by owners who have just sold an active licence and purchase a remaining, but inactive licence, entering other fisheries with overcapacity, new entrants, new investment in remaining vessels and increased fishing by relatively inactive vessels and licences. Such second-best measures limit gains in economic efficiency. Scrapping of decommissioned vessels, or requiring their commitment to a non-fishing use, are often critical elements of a buyback programme, and are almost always recommended. In some instances, a limit on fishing time may be required to keep capital and capacity utilization from aggravating the overcapacity and overfishing problem. In some cases, modernization in the form of vessel construction, and hence embodiment of new technology in a new capital stock, is allowed only with the removal of an equivalent amount of fishing capacity, as measured by one or more components of the heterogeneous capital stock, such as vessel tonnage or engine power (horsepower or kilowatts). Buybacks that facilitate financing vessel replacement and modernization have greater difficulty in achieving capacity reduction.

Sixteenth, buyback programmes be evaluated to identify lessons learned that might help improve future programmes.[21] Planning for such evaluations, including developing measures to evaluate programme results, should be an important part of the design of future programmes. In addition, performance measures for buybacks that relate to programme goals and broader legislative goals, such as the need to better manage fishing capacity and sustain fish stocks, should be developed.

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[21] This recommendation draws almost verbatim from GAO (2001: 5-6). The papers of Kitts and Thunberg (no date) and Kitts, Thunberg and Robertson (1998, 2000) are extremely useful for practical design and evaluation.

9. CONCLUDING REMARKS

In sum, buybacks of vessels, licences, access and other use rights or gear have been demonstrated to be a useful policy tool in certain circumstances. Although buybacks are not a panacea, they can accelerate the transition to a rationalized fishery managed on the basis of stronger use and property rights and enhanced ecosystem health, when coupled with limited access, scrapping of bought-out vessels and limits on purchases of formerly inactive licences by owners who have just sold active licences. Co-management through design in partnership with the industry is critical.

Buybacks can be viewed as a strategic policy tool in the transition to longer-term conservation and management built on strengthened use and property rights. Following an effective buyback, they can provide a window of opportunity that helps transform behavior from uncooperative to more cooperative, and replace expensive and often ineffective centralized command-and-control fishery management measures with more decentralized private incentives for fishers that are more closely aligned with social goals. Lesser numbers of licence holders, who are not driven to desperation and immediate short-term behavior by financial losses, can begin to coalesce and to act like *de facto* collective owners of the resource. Dividing the fishery into smaller units (gears, areas, *etc.*) to keep the number of players limited contributes in this regard. Self-enforcing voluntary agreements among groups aimed at conservation and management purposes can play an important role, and are aided by buybacks. These are expected to increase in the future, when a full property-rights approach is infeasible, and, in fact, to form common-use rights.

Left solely to themselves over a longer time period, however, buybacks by themselves do not solve the "race-to-catch-fish" incentives of incomplete use or property rights. Unless specific steps are taken, previously-inactive vessels and permits will likely be used, and the gains from the buybacks eroded. Moreover, continuous, on-going buybacks (facing rising vessel and licence prices as expected future resource rent is capitalized in the value of the vessel and licence) and automatic attrition through reductions in some specified percent of vessel capacity units with every vessel transfer would need to be a permanent feature. Such continuous structural adjustment counters the on-going increases in fishing capacity as fishers invest and substitute uncontrolled for controlled inputs ("capital stuffing") and adopt new technology, driven by reinforcement of the incentives of open access over the longer term.

Buybacks of vessels, licences, and access to modes of fishing may have a special role to play in transnational fisheries as a strategic policy tool to address overcapacity and potential or actual overexploitation of resource stocks, for which use and property rights and international law are not supportive of a stronger use- or property-right approach, but for which limited access is emerging out of customary law. Buybacks can also target methods of fishing with adverse ecological impacts. Self-enforcing voluntary agreements targeted as specific conservation and management measures, such as incidental bycatch from sets on floating objects, may make a promising contribution if entry and free-riding can be tackled in a satisfactory way. Buybacks can also help set the stage for voluntary agreements. Buybacks also provide a compensation mechanism for players in the industry that would otherwise lose out from rebuilding fish stocks, addressing environmental issues and restructuring the industry. Side payments providing compensation, and addressing the asymmetries between coastal states and distant-water fishing nations are critical to achieve multilateral cooperation and participation in buybacks. Buybacks can also help restructure the industry to satisfy social and ecological objectives.

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FAO FISHERIES PROCEEDINGS **8**

Methodological Workshop on the Management of Tuna Fishing Capacity

Stock status, data envelopment analysis, industry surveys and management options

8–12 May 2006
La Jolla, California, United States of America

These Proceedings include the report and papers presented at the Methodological Workshop on the Management of Tuna Fishing Capacity – Stock status, data envelopment analysis, industry surveys and management options, which was hosted by the Inter-American Tropical Tuna Commission in La Jolla, California, United States of America, from 8 to 12 May 2006. It also contains a statement prepared by the participants and presented at the Meeting of Tuna Regional Fisheries Management Organizations held in Kobe, Japan, in January 2007.

The purpose of the workshop, organized in collaboration with tuna agencies and programmes, was to develop quantitative methods to determine the desired magnitude of or desired change to fishing capacity on the basis of the status of stocks. The outcome of the workshop is relevant for the work of these organizations and their member countries, providing technical assistance in managing tuna fishing capacity.

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